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COMPILATION OF SAFETY SEPARATION DATA ON BULK EXPLOSIVES AND MUNITIONS

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FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

Minimum nonpropagation distance	Bulk explosives	Composition C4
Safe separation	Munitions	Guanidine Nitrate
MMT ammunition	Composition A7	TNT (cont)

19. ABSTRACT (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

Safe separation tests on eight bulk explosives and 17 types of munitions were conducted to provide safety data for the upgrading of manufacturing technology. The configurations examined were applicable to different stages of munitions manufacturing at various Army Ammunition Plants (AAPs) and contractor facilities. This report is the compilation of safe separation distances of all bulk explosives and munition types that have been established to date. It provides a constant format which is easily accessable and a comprehensive and ready reference for engineers, safety analysts, project leaders, and manufacturing personnel.

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18. SUBJECT TERMS (cont)

8-inch M509 HE projectile
155 mm M795 HE projectile
81 mm M374 HE projectile
BLU-97/B bomblet
Composition A5
Cyclotol
8-inch M106 HE projectile
155 mm M549 HERA projectile
81 mm M374A2E1 HE cartridge
BLU-63A/B bomblet
M74AP/M75 ATAV mine
155 mm M483 HE projectile
105 mm M456 HEAT-T projectile
25 mm M792 HEI-T cartridge
M56 mine
Composition B
Nitroguanidine
155 mm M107 HE projectile
105 mm MIHE projectile
30 mm M789 HEDP projectile
M42/M46 GP grenades

SUMMARY

The bulk explosives and munition types, the specific configurations examined, and the established safe separating distances are listed in the following table. For all items/configurations examined, unless individually specified, the test conditions were: (1) in free air (without tunnels), (2) open spaced (no shields), (3) in a vertical orientation, and (4) measured edge to edge. Also the reported distances, unless specified (**), are the minimum spacing obtainable.

Bulk explosive	Configuration	Distance Meter	Distance Feet
Composition A5	4.5 kg (10 lb) in rubber buckets with tunnel	1.83	6.0
	6.8 kg (15 lb) in aluminum buckets with tunnel	6.10	20.0
Composition A7	76.2 kg (168 lb) in steel tote bins with tunnel	>39.6*	>130.0*
Composition B	Flake, critical depth on 381mm (15 in) serpentix conveyor	<0.055	<0.17
	1.13 kg (2.5 lb) riser scrap:		
	2 pieces	0.46	1.5
	4 pieces	0.91	3.0
	2 pieces within funnels	0.61	2.0
	4 pieces within funnels	0.91	3.0
	27.2 kg (60 lb) with tunnel:		
	in cardboard container	3.66	12.0
	in plastic buckets	3.66**	12.0**
Composition C4	15.9 kg (35 lb) in aluminum buckets with tunnel	6.10**	20.0**
	27.2 kg (60 lb) in carboard box with tunnel	7.62**	25.0**
Cyclotol (75/25)	27.2 kg (60 lb) in aluminum box with tunnel and shield[1]	7.32	24.0
	22.7 kg (50 lb) in cardboard box with tunnel	5.49	18.0
Guanidine nitrate (powder)	All in DOT-21C-60 containers with tops on:		
	9.1 kg (20 lb)	1.14	3.8
	18.1 kg (40 lb)	1.47	4.8
	36.3 kg (80 lb)	1.68	5.5

Bulk explosive	Configuration	Distance Meter	Feet
Nitroguanidine	All in DOT-21C-60 containers with tops on:		
	11.3 kg (25 lb)	1.68	5.5
	22.7 kg (50 lb)	2.13	7.0
	204.1 kg (450 lb)	>4.88*	>16.0*
TNT, type 1, flake	Critical depth on 0.61 mm (2 ft) serpentix conveyor	<0.025	<0.08
	24.9 kg (55 lb) in cardboard box	3.66	12.0
	76.2 kg (168 lb) in aluminum tote bin with steel-fiberglass tunnel	18.3	60.0
	76.2 kg (168 lb) in aluminum tote bin with wood tunnel	15.2	50.0

Munition	Configuration	Distance Meter	Distance Feet
M106 HE projectile 8 inch	Single round	>3.05*	>10.0*
	Single round with shield[2]	0.30	1.0
M509 HE projectile 8 inch	Single round with shield[3]	>1.52*	>5.0*
	Single round with V-shield[4]	0.82	2.7
M107 HE projectile 155 mm	Single round	>2.13*	>7.0*
	Single round with shield[5]	0.46	1.5
	Single round, horizontal	>1.52*	>5.0*
	24 per pallet	33.5	110.0
	24 per pallet with funnels	>42.7*	>140.0*
	24 per pallet, with funnels and shield[6]	>33.5*	>110.0*
M483 HE projectile 155 mm	Single round	>1.52*	>5.0*
	Single round with shield[7]	>0.91*	>3.0*
	Single round with MS shield[8]	0	0
M549 HERA projectile, 155 mm	Single round	1.52	5.0
	Single round with shield[2]	0.09	0.29
	8 per pallet	>9.14*	>30.0*
	8 per pallet with shield[2]	3.05	10.0
M795 HE projectile 155 mm	Single round	4.57	15.0
M1 HE projectile 105 mm	16 per pallet	9.14	30.0
	16 per pallet with funnel	>12.2*	>40.0*
	16 per pallet with funnel and shield[6]	6.10	20.0
M456 HEAT-T projectile, 105 mm	Primed cartridge cases	0	0
	Single round with shield[2]	0.49	1.6
	Single round, horizontal, with shield[2]	0.28	0.91
M374A2E1 HE cartridge, 81 mm	Single round with shield[9]	0.22**	0.73**

Munition	Configuration	Distance Meter	Distance Feet
M374 HE projectile, 81 mm	Single round	0.61	2.0
	Single round with shield[10]	0.22**	0.73**
	72 per pallet	9.14	30.0
XM789 HEDP projectile, 30 mm	2 each PBXN-5 pellets	0.025	0.08
	Shell body with 2 pellets	0.025	0.08
	Loaded body assembly	0.025	0.08
	Heated loaded body assembly	0.076	0.25
	Fuzed projectile	0.076	0.25
	Heated fuzed projectile	>0.40	>1.3
XM792 HEI-T cartridge, 25 mm	Type I pellets	0.025	0.08
	Type II pellet	0.013	0.04
	Loaded body assembly	0.051	0.16
	Fuzed projectile	0.051	0.16
	Complete cartridge	0.051	0.16
BLU-63 A/B bomblet	Hemispheres	0.013	0.04
	Hemispheres in fixtures	0	0
	Hemispheres, 16 per tray	0	0
	Bomblet	0.051	0.16
BLU-97/B submunition	16 per pallet	>4.57*	>15.0*
	16 per pallet with shield[11]	1.22	4.0
	16 per pallet with airflow shield[12]	1.52	5.0
	Single bomblet with either 100% or 75% shield[13]	0.23	0.75
M42/M46 GP grenades (without fuzes)	Single grenade	0.051	0.16
	64 per tray	2.13	7.0
	768 per carrier with tunnel	12.2	40.0
	8 per M483 ring pack	0.30	1.0
	15 per M509 ring pack	0.46	1.5
	32/64 per single/dual cluster tray	0	0
M56 mine	Single mine	0.15**	0.50**
	2 mine canister	0.15**	0.50**

Munition	Configuration	Distance Meter	Distance Feet
M74AP and M75ATAV mines (without fuzes)	Single mine	>2.59*	>8.5*
	Single mine with shield[14]	0.076	0.25

SUMMARY TABLE NOTES

General: * Maximum distance tested.
** Not minimum distance.

Shields:

[1] 9.65 mm (0.38 in.) thick kevlar.

[2] 76.2 mm (3 in.) diameter aluminum (6061-T6) bar.

[3] 25.4 mm (1 in.) thick steel (1020) plate.

[4] See figure A.

[5] 25.4 mm (1 in.) thick aluminum or 12.7 mm (0.5 in.) thick steel plate.

[6] 19.05 mm (0.75 in.) thick steel (1020) plate.

[7] Empty 155 mm M483 HE projectile body.

[8] See figure B.

[9] 6.35mm (0.25 in.) thick lexan plate extension to note 10 projectile shield.

[10] 50.8 (2 in.) thick aluminim (6061-T6) brick.

[11] 12.7 mm (0.5 in.) thick aluminum (6061-T6) plate.

[12] 12.7 mm (0.5 in.) thick aluminum (6061-T6) plates, cut in open picket-fence design with one plate's spaces covered by the second plate's columns.

[13] 12.7 mm (0.5 in.) thick aluminum (6061-T6) plate.

[14] 7.62 mm (3 in.) thick aluminum (6061-T6) brick.

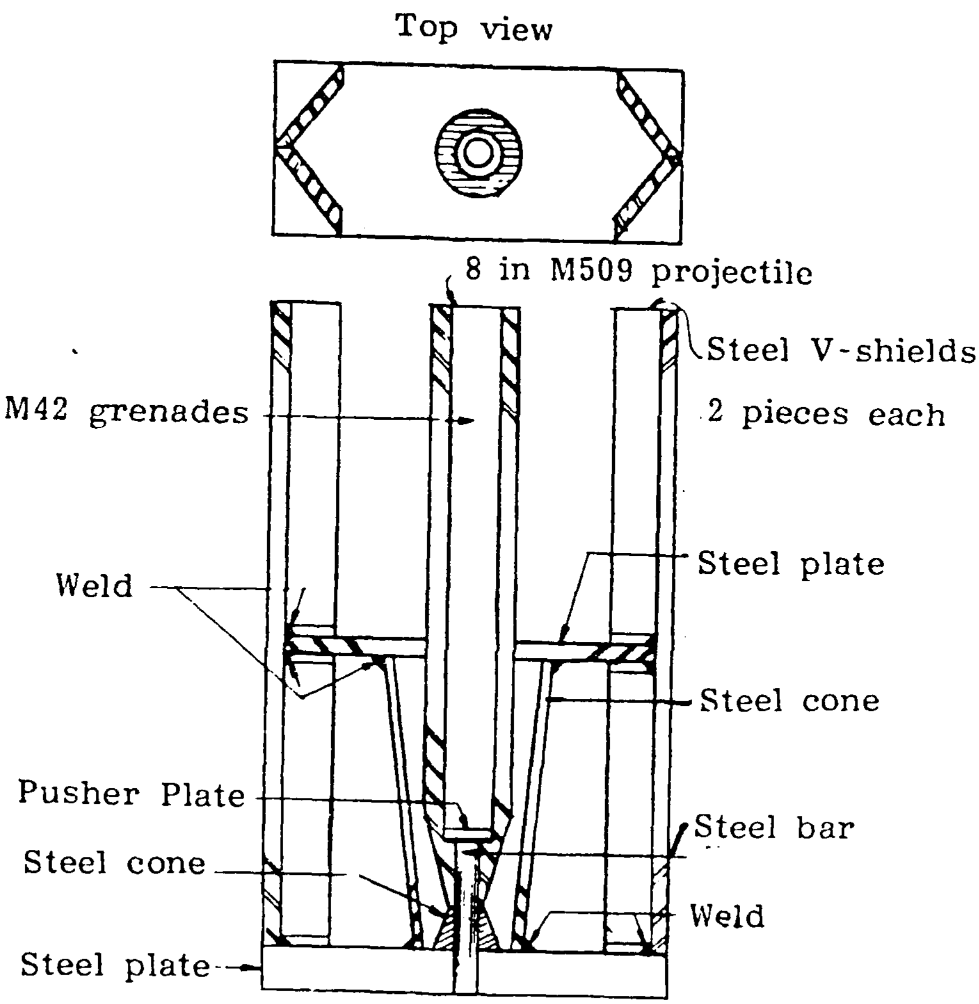

Figure A. V-shield transfer pallet

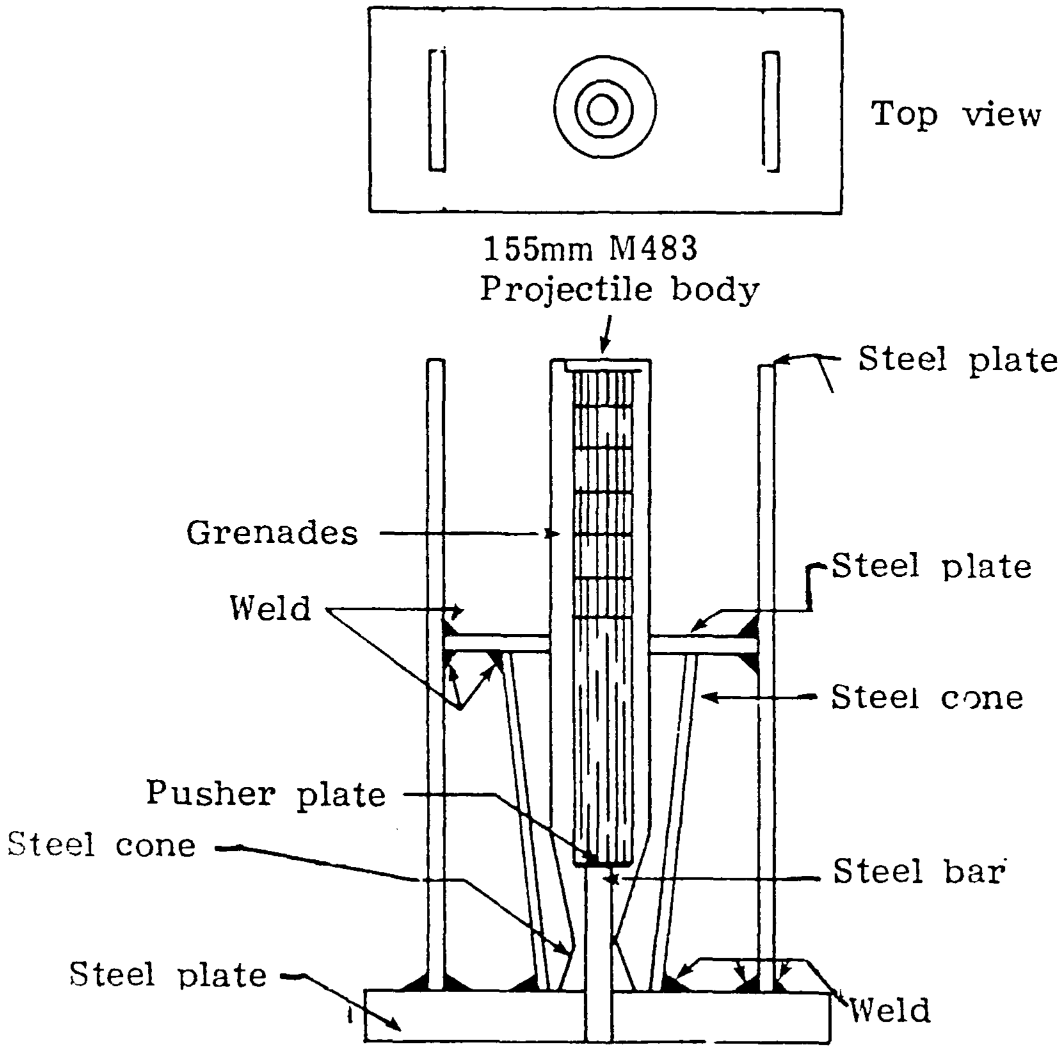

Figure B. MS pallet

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INTRODUCTION

Background

An Army-wide expansion program was initiated to upgrade existing explosive manufacturing and LAP (load, assemble, and pack) facilities and develop new ones. Substantial increases in the production cost-effectiveness and improvement in facility safety were the major goals of this program. Part of this overall program was to develop safety criteria. The program entitled "Safety Engineering in Support of Ammunition Plants" provides some of the criteria to be used in the design of future explosive production installations.

This program was undertaken to determine a means of safely handling and transporting bulk explosives by means of conveyors between automated inspection buildings and melt/pour facilities. Concurrently, similar programs were in progress to determine safe separation distances between projectiles and components being conveyed between work stations of LAP facilities.

The primary objective was to determine the safe spacing between unprotected bulk explosives in various configurations and munitions. Whenever it was necessary, shield protection was used to reduce the safe separation spacing of acceptable distances.

Objective

The objective was to compile all of the readily available safe separation distance data on bulk explosives and munitions. This report provides a consistant format which is easily accessable and provides a comprehensive and ready reference for engineers, safety analysts, project leaders, and manufacturing personnel.

General Testing Methodology

Testing of bulk explosives and munitions was conducted to determine and statistically confirm, in most cases, the minimum safe separation distance between explosive items under simulated manufacturing conditions. The individual test programs were predicated upon a given manufacturing operation where improved safety criteria would lessen the probability of a catastrophic event. Details as to the orientation of the test article, confinement of the surroundings, peripheral equipment such as conveyors that may cause secondary fragmentation, additional explosive elements such as riser funnels, and the particular manufacturing process were taken into account in developing the individual test plans. The basic test plan was then divided into several phases to simulate various line conditions, with both exploratory and confirmatory tests conducted for each phase. If the confirmatory distance exceeded the design requirements of that particular facility or manufacturing process, the same tests would then be reconducted using

shielding to reduce the distance even further. Each configuration is discussed in more detail in its individual section.

Exploratory Tests

Initially, in the exploratory phase, the acceptor items were spaced at predetermined distances where it is believed a propagation of the detonated donor would occur. Acceptor detonation was confirmed by visual post-test examinations of the items and, in some cases, verified qualitatively with the aid of the witness plate in which the signature of the acceptor reaction is firmly imprinted. If propagation of the donor detonation does not occur at this initial distance, the spacing is decreased until an actual detonation propagation of an acceptor occurs; then, the spacing is increased until there is no detonation propagation to an acceptor. Once the minimum spacing has been empirically derived, the confirmatory phase is begun.

Confirmatory Tests

The number of confirmatory tests was generally predicated upon the propagation of an acceptor item to conform, with few exceptions, to a maximum upper limit of 10% probability of a detonation propagation occurrence at a confidence level of 95%. The lower limit would be 0% propagation for all confidence levels. An observation, or data point, was obtained for each acceptor placed about the donor with all acceptors being the same distance from donor. Based upon the 95% confidence level, usually a minimum of 50 observations were made for each configuration being evaluated. Assessment of the confirmatory tests was determined strictly on the basis of nonpropagation of the donor detonation to the acceptors.

Methods of Initiation

Validity of safe separation data was based upon the donors detonating high order when initiated. Generally, the bulk explosives and munitions were received without an initiating source; therefore, a standardized explosive fuze train was devised for all safe separation testing. This fuze train generally consisted of an electric blasting cap, a booster charge (when necessary), and the main charge or donor item. The blasting cap was basically one of three types (J-2 commercial cap, M6 military cap, or a number 8 cap), dependent upon availability; however, on occasion, primacord with a M2 fuze lighter was used. The most common booster was composition C4, the weight of which was tailored to just make the main charge go to a high order detonation. The booster was usually placed on top of the main charge, or buried in it, for bulk explosives and placed into the normal fuze booster cavity of munitions.

In the case of multiunit donors, usually only a single item was initiated with the other donor units reacting due to sympathetic detonation. In all cases, the simpliest possible explosive train that would assure complete high order initiation of the donor was employed, assuring that

the initiating source did not significantly contribute to the test results.

Criteria for Acceptance

The only acceptable criterion for determining the safe separation distance was the non-propagation of the donor detonation to the acceptors. The safe separation distances, as used throughout this compilation, are defined as the edge-to-edge measured spacing between the donor and acceptors, not centerline distances.

Probability Analysis

Variation in manufacturing tolerances, materials, wear, etc., the economics of performing large numbers of tests, and variations in interpretations from visual observations require that statistical means be enlisted in the interpretation of the test data. The actual probability of the propagation occurrences in a particular test configuration as related to the total number of tests conducted.

The probability of the propagation of an explosive incident is dependent upon the degree of certainty or confidence level involved and has both upper and lower limits. The lower limit for all confidence levels is zero; whereas, the upper limit is a function of the number of observations, data points, or acceptors successfully tested. Since each observation is independent of the others and has a constant probability of a reaction occurrence (explosive propagation), the number of reactions (x) in a given number of observations (n) will have a binominal distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be presented mathematically by

$$p = x/n$$

and, therefore, the expected value of x is given by

$$E(x) = np$$

Each confidence level will have a specific upper limit (p_2) depending upon the number of observations involved. The upper limit for a given confidence level (α), when a reaction is not observed, is expressed as

$$(1 - p_2)n = E$$

where

$$E = (1 - \alpha)/2 \text{ and } \alpha < 1$$

The probability limits for different numbers of observations at three different confidence levels is shown in figure 1. Note that only the 95% confidence level is used within this report.

BULK EXPLOSIVES

Composition A5 in Rubber and Aluminum Buckets (refs 1 and 2)

Objective

The objective was to establish the minimum safe separation distances for 4.5 kg (10 lb) quantities of Composition A5 in rubber buckets and 6.88 kg (15 lb) quantities in aluminum buckets on overhead conveyors and in simulated interbuilding tunnels.

Test Specimen

Composition A5, bulk, type 1 (RDX and stearic acid) was used. The material was tested in open top rubber buckets that were 337.8 mm (13.3 in.) in height, varied in diameter from 182.9 to 241.3 mm (7.2 to 9.5 in.), and made from layers of canvas covered with conductive rubber. The explosive was tested in open and closed topped aluminum buckets that were standard 18.9L (5 gal) containers. .

Test Arrangements

The 4.5 kg (10 lb) tests in open top rubber buckets used the setup shown in figure 2. The tunnels were constructed with a wooden frame covered with corrugated fiberglass panels and were 3.66 m (12 ft) square with sufficient length to contain the three buckets. The buckets were placed on a pine board to simulate a conveyor at a height of 3.26 m (10.7 ft) above the ground and 0.3 m (1 ft) from the wall.

The 6.8 kg (15 lb) tests in open top aluminum buckets used the test setup shown in figure 3. The tunnels were constructed of angle iron and covered with 13- to 22-gage aluminum sheets and were 2.44 m (8 ft) square. The aluminum buckets were suspended from an I-beam and were 1.83 m (6 ft) from the ground.

Test Results

Using the 4.5 kg (10 lb) open rubber buckets, a series of tests at distances ranging from 0.61 to 3.66 m (2 to 12 ft) were conducted with propagations occurring at 1.52 m (5 ft) and below. Therefore, the confirmatory tests were conducted at a distance of 1.83 m (6 ft), resulting in a upper limit of 6.9% probability of propagation at the 95% confidence level.

Using the 6.8 kg (15 lb) open aluminum buckets, a series of exploratory tests were conducted at distances ranging from 3.05 to 6.1 m (10 to 20 ft) with propagations occurring at 4.57 m (15 ft) and below. Therefore, the confirmatory tests were conducted at a distance of 6.1 m resulting in an upper limit of 6.2% probability of propagation at the 95% confidence level.

A series of tests were conducted using 6.8 kg (15 lb) in tightly sealed aluminum buckets. These tests used a separation distance of 6.1 m without any propagations.

Conclusions

Open rubber buckets containing 4.5 kg of explosive A5 on an overhead conveyor in interbuilding tunnels should be spaced a minimum of 1.83 m.

Open aluminum buckets containing 6.8 kg of explosive A5 on a pendant conveyor within a tunnel should be spaced a minimum of 6.1 m.

Composition A7 in Tote Bins (refs 3 and 4)

Objective

The objective was to determine a nonpropagation configuration and distance for transporting 76.2 kg (168 lb) of Composition A7.

Test Specimen

Composition A7 in bulk (granulated powder) form was used with each tote bin containing 76.2 kg of explosive. The tote bins were fabricated from stainless steel type 304, 1.88 mm (0.074 in.) thick and measuring 609.6 mm (24 in.) by 457.2 mm (18 in.) square, with a hinged plexiglass lid on top.

Test Arrangements

The 76.2 kg of Composition A7 in the tote bins were tested in tunnels (fig. 4) constructed from a wooden frame and sheathed with corrugated fiberglass sheets. The tunnels were

constructed in modular section 2.13 m (7 ft) wide by 2.74 m (9 ft) high and 2.44 m (8 ft) long, with sufficient sections joined to form the required tunnel length. The maximum lengths were 39.0 mm (128 ft). Each tote bin was suspended 1.47 m (4.8 ft) above the ground and was placed on a section of steel roller conveyor.

Test Results

Tests were conducted with separation distances ranging from 6.1 to 39.6 m (20 to 130 ft), the maximum acceptable distance, with detonation propagations occurring at all distances tested.

Conclusions

Stainless steel tote bins containing 76.2 kg (168 lb) of Composition A7, if spaced at 39.6 m or closer, risks the propagation of any detonation.

Critical Depth of Composition B (ref 5)

Objective

The objective was to develop a means to prevent propagation of an accidental detonation from one part of a conveyor carrying loose Composition B to another by using simple and economical modifications; to examine the effect of variations in depth and width of explosive on the conveyor; and whether the construction of the conveyor has an effect on propagations.

Test Specimen

Flake Composition B, grade A, type I was used.

Test Arrangements

This program was divided into four separate test series:

1. Wooden or rubber troughs in hemispherical tunnels.

This series used covered conveyors that simulated the confinements produced by the dust collection system. Each hemispherical cover was 0.61 m (2 ft) wide by 0.91 m (3 ft) high and made from aluminum sheets. The conveyor was simulated by either rubber or wooden troughs suspended 330.2 mm (13 in.) above the ground. Two conveyor widths [285.8 and 444.5 m (11.3 and 17.5 in.)] and four different lengths [varying from 1.52 to 4.88 m (5 to 16 ft)] were used. Composition B was leveled at depths that varied from 25.4 to 50.8 mm (1 to 2 in.)

2. Wooden or rubber troughs in square tunnels.

This series used a square aluminum tunnel (0.61 by 0.91 m) with all the simulated conveyors made of wood. Since complete propagations occurred in all the tests of the first series, interrupters were used. The first interrupters were 76.2 mm (3 in.) high by 6.3 mm (0.25 in.) thick rubber pads. A pair of rubber cleats was used to form an airgap between explosive segments. The length of the airgaps varied from 76.2 to 609.6 mm (3 to 24 in.).

3. Conveyor airgaps.

This series used the airgap system from the second series. Two airgap designs were tried: (1) a square box-like design consisting of two 38.1 mm (1.5 in.) high rubber cleats spaced 101.6 mm (4 in.) apart with a 3.18 mm (0.125 in.) thick rubber sheet glued to the top, (2) a round design consisting of a 1.59 mm (0.063 in.) thick steel plate bent to a 127 mm (5 in.) radius with a 3.18-mm thick rubber sheet bonded to it (fig. 6). In all tests, the simulated conveyors were supported at a height of 381 mm (15 in.) above the ground. Also in a few cases, powdered Composition B was placed on the airgap area to create a more hazardous condition.

4. Corrugated conveyor.

This series used a corrugated (serpentix type) rubber conveyor where the explosives in adjacent troughs were separated by a 50.8 mm (2 in.) air gap when the depth of explosive was less than the depth of the corrugations. The conveyors were supported at a height of 0.76 m (2.5 ft) above the ground and used two depths of explosives: 50.8 mm (2 in.) on a 431.8 mm (17 in.) wide conveyor and 38.1 mm (1.5 in.) on a 381 mm (15 in.) wide conveyor.

Test Results

In the first series varying explosive depths on a confined conveyor, all tested conditions resulted in detonation propagations. Several general observations were made: (1) for a given depth of explosive, the wider the conveyor, the more severe the detonation; (2) the intensity of the detonation is proportional to the depth of explosive; (3) for shallower depths, the detonation propagation subsided in a fraction of the conveyor's length; and (4) for greater depths, the entire conveyor was engulfed in a fireball. Since propagations occurred under all conditions, this approach was considered ineffective.

The second series, using rubber cleats to separate the explosives, also proved to be ineffective and was discontinued after the donor detonation propagated the full length of the conveyor in all cases. This followed the initial airgap trials where an airgap between explosives was formed by using two rubber cleats in which the depth of explosive varied from 38.1 to 69.9

mm (1.5 to 2.8 in.) and the spacing between explosive batches ranged from 76.2 to 609.6 mm (3 to 24 in.). Since there was no detonation propagations, this lead to the third series where the square and round 101.6 mm (4 in.) airgap spacers were examined. This airgap system underwent sufficient testing; the upper limit of probability of propagation was 15% at the 95% confidence level.

The final series, using corrugated (serpentix type) conveyors that provided a minimum of 50.8-mm air gap between explosives, only had propagations occurring with a 50.8-mm depth of explosive. With a 38.1 mm depth of explosive, the probability of propagation was an upper limit of 11% at the 95% confidence level.

Conclusions

Detonation propagation along a conveyor was dependent upon explosive depth and conveyor width. The shallower the depth and greater the width, the lower the probability of propagation of an explosive occurence. Also, a 38.1 mm depth of explosive on a 381-mm wide corrugated (serpentix type) rubber conveyor or a 101.6-mm airgap between adjoining batches would prevent explosive propagation.

Composition B Riser Scrap (ref 6)

Objective

The objective was to determine the safe separation distances between quantities of riser scrap that were removed from 105 mm M1 projectiles and transported by conveyor both with and without pouring funnels.

Test Specimen

Various amounts of Composition B riser scrap were used. Each piece consisted of 1.13 kg (2.5 lb) of Composition B (60 RDX/40 TNT) formed in the shape of the casting funnel. The funnel was 270 mm (10.6 in.) long and varied in diameter from 47.8 to 104.8 mm (1.9 to 4.1 in.) on the outside, with a wall thickness of 3.81 mm (0.15 in.), and was made of zamac, a soft zinc alloy.

Test Arrangments

For two risers without funnels, each test consisted of a linear array (fig. 7) with the separation distance varied from test to test and ranging from 76.2 mm to 2.44 m (3 in. to 8 ft). The simulated conveyor was constructed of pine boards and was suspended 406.4 mm (16 in.) above the ground. The cleats were conveyor belt rubber cleats, 76.2 mm high and cut to fit the

width of the conveyor.

For four risers without funnels, the distances used in the exploratory testing ranged from 76.2 mm to 0.91 m (3 in. to 3 ft). The test array was the same as in figure 7 except that four risers were used at each location.

For two risers with funnels, the exploratory test distances ranged from 304.8 to 487.7 mm (12 to 19.2 in.). The final test series was for four risers with funnels, with exploratory test distances ranging from 0.46 to 0.91 m (1.5 to 3 ft).

Test Results

For the two risers without funnels series, the confirmatory tests were conducted at a 457.2 mm (18 in.) distance without a propagation; therefore, the upper limit probability of propagation is 7.8% at the 95% confidence level.

For the four risers without funnels series, the confirmatory tests were conducted at 0.91 m distance without a propagation; therefore, the upper limit probability of propagation was 4.8% at the 95% confidence level.

For the two risers with funnels, the confirmatory tests were conducted with a distance of 609.6 mm (24 in.) without a propagation, resulting in an upper limit of 5.9% probability of propagation at the 95% confidence level.

For the four risers with funnels, the confirmatory tests were conducted with a distance of 0.91 m without a propagation, resulting in an upper limited of 6.7% probability of propagation at the 95% confidence level.

Conclusions

The minimum safe spacing for two scrap risers without the funnels was 457.2 mm and for the four scrap risers without funnels, 0.91 m. For two Composition B risers contained within funnels, the safe separation distance was 609.6 mm (24 in.); for four Composition B risers contained within funnels, the safe separation distance was 0.91 m.

Boxes of Composition B (ref 7)

Objective

The objective was to establish the safe separation distance between shipping boxes containing 27.2 kg (60 lb) of Composition B on enclosed conveyors.

Test Specimen

A standard fiberboard shipping box measuring 476.3 by 362 by 193.7 mm (18.8 by 14.3 by 7.6 in.) and containing 27.2 kg (60 lb) of Composition B was used.

Test Arrangements

All tests were conducted within 0.91 m (3 ft) diameter hemisphere aluminum tunnels (fig. 8), and with the boxes located 0.46 m (1.5 ft) above the ground on a steel roller conveyor.

Test Results

The tests were conducted at distances ranging from 2.44 to 3.66 m (8 to 12 ft) with propagations at the 2.44-m distance. Therefore, the safe separation spacing was established at 3.66 m with an upper limit of 6.7% probability of propagation at the 95% confidence level.

Conclusions

The safe spacing for fiberboard boxes containing 27.2 kg of Composition B within tunnels was 3.66 m.

Buckets of Composition B (ref 8)

Objective

The objective was to establish the safe separation distance between buckets containing 27.7 kg (60 lb) of bulk Composition B on a conveyor.

Test Specimen

Molded phenolformaldehyde plastic buckets that were 3.18 mm (0.125 in.) thick, 406.4 mm (16 in.) in diameter, and 355.6 mm (14 in.) high with lids of the same material were used. Each bucket contained 27.2 kg of grade A, bulk, flake type Composition B.

Test Arrangements

All tests were conducted within tunnel structures fabricated from steel framing and covered with 24-gage corrugated steel sheeting (fig. 9). A steel beam was attached to the ceiling of the tunnels with the buckets suspended so that they were 1.52 mm (5 ft) from the ground.

Test Results

The tests were conducted at a spacing of 3.66 m (12 ft) without any propagations occurring. This resulted in an upper limit of 16.8% probability of propagation at the 95% confidence level.

Conclusions

Plastic buckets containing 27.2 kg of Composition B and contained within a steel sided tunnel can safely be spaced 3.66 m apart.

Composition C4 (ref 9)

Objective

The objective was to determine the safe separation between buckets of Composition C4 as transported through various loading operations.

Test Specimens

Bare extruded block Composition C4 was placed in open aluminum 18.9 L (5 gal.) buckets measuring 355.6 mm (14 in.) in diameter by 508.0 mm (20 in.) deep. Two quantities of Composition C4 were used [15.9 and 22.7 kg (35 and 50 lb)].

Test Arrangments

All testing was conducted within simulated tunnels (fig.10) that measured 2.44 m (8 ft) wide by 3.05 m (10 ft) high and were 17.1 m (56 ft) long. The tunnels were covered with 26-gage corrugated steel sheets and contained a central "I" beam for the pendant conveyor. The explosive loaded buckets were hung from the pendant conveyor at a distance of 2.13 m (7 ft) from the ground.

Test Results

The 15.9 kg (35 lb) buckets were tested at a distance of 6.1 m (20 ft) without any propagations; therefore, the upper limit was 16.8% probability of propagation at the 95% confidence level. For the 22.7-kg buckets, the tests were conducted at a distance of 7.62 m (25 ft) without any propagations and resulting in an upper limit of 16.8% probability of propagation at the 95% confidence level.

Conclusions

The safe spacing for Composition C4 transported in aluminum buckets within sheet steel tunnels was 6.1 and 7.62 m (20 and 25 ft) for 15.9 and 22.7 kg (35 and 50 lb) quantities, respectively.

Cyclotol (ref 10)

Objective

The objective was to establish the safe separation distances which will prevent propagation of detonation between fiberboard shipping containers or aluminum boxes filled with cyclotol explosives on enclosed conveyors.

Test Specimen

Cyclotol Type 1 (75/25), packaged in 27.2 kg (60 lb) fiberboard containers on steel roller conveyors, and the same explosive quantity packaged in aluminum boxes on pendant conveyors were used.

Test Arrangements

For the fiberboard containers on steel roller conveyors, tunnels constructed with steel framing and sheathed with 0.89 mm (0.035 in.) thick corrugated fiberglass and 2.44 m (8 ft) square by 14.6 m (48 ft) long were used. Also, each donor container had a 1.52 m (5 ft) section of steel roller conveyor under it and all containers were suspended 0.79 m (2.6 ft) above the ground.

For the aluminum boxes on pendant conveyors, the tunnels were the same construction as for the fiberboard containers; the aluminum boxes were initially constructed of 6061-T6 and then 7075-T6 aluminum 2.31 mm (0.091 in.) thick and 393.7 mm (15.5 in.) wide by 457.2 mm (18 in.) long by 228.6 mm (9 in.) high. As with the fiberboard container tests, the aluminum boxes were suspended by 0.79 m (2.6 ft) above the ground.

Test Results

For the fiberboard containers on steel roller conveyors and within steel/fiberglass tunnels, the tests were conducted at distances from 2.3 to 5.5 m (7.6 to 18 ft). There were detonation propagations occurring at distances of 4.6 m (15 ft) and below. Therefore, the safe separation distance was established as 5.49 m (18 ft) with an upper limit of 8.4% probability of propagation at the 95% confidence level.

For the aluminum boxes, small quantities of tests were conducted using various grades of aluminum (6061-T6 and 7075-T6) and thicknesses [2.31 to 7.11 mm (0.091 to 0.28 in.)] and using various shielding materials (steel and kevlar). The final configuration was 7075-T6 aluminum, 2.31 mm thick with a 9.65 mm (0.38 in.) kevlar shield, with tests conducted at a distance of 7.32 m (24 ft). This produced an upper limit of 13.7% probability of propagation at the 95% confidence level.

Conclusions

Bulk cyclotol in 27.2 kg quantities in fiberboard shipping containers can be safely transported along steel roller conveyors within steel/fiberglass tunnels, if a distance of 5.49 m (18 ft) is maintained between containers. Also, the same quantity of explosive in aluminum (7075-T6) boxes can be safely transported on a pendant conveyor, if a distance of 7.32 m (24 ft) is maintained between boxes and a kevlar shield is inserted between boxes.

Nitroguanidine and Guanidine Nitrate (ref 11)

Objective

The objective was to provide the minimum safe separation distance criteria for various configurations of nitroguanidine and guanidine nitrate being transported during production operations.

Test Specimens

Both nitroguanidine and guanidine nitrate were in bulk powder form within DOT-21C-60 fiber shipping drums and with their tops on.

Test Arrangements

Nitroguanidine. For 22.7 kg quantities, a series of tests with four acceptors was conducted using the array in figure 11; for 11.3 kg (25 lb) quantities, tests were conducted as shown in figure 12; and for the 204.1 kg (450 lb) quantities, the test was conducted with the palletized configuration shown in figure 13.

Guanidine Nitrate. For 9.1 kg (20 lb) quantities, a series of tests were conducted as shown in figure 11. For the 18.1 and 36.3 kg (40 and 80 lb) quantities, the test configuration shown in figure 12 was used in both cases.

Test Results

Nitroguanidine. The initial tests for the 22.7 kg quantities were conducted at a spacing of 1.47 m (4.8 ft). However, after detonation propagation, the distance was increased to 2.13 m (7 ft) and no other propagations occurred. All the testing of the 11.3 kg (25 lb) quantities was conducted at a distance of 1.68 m (5.5 ft) without any propagations or burning occurrring; however, in each case the fiberboard container was destroyed. The final configuration for 204.1 kg (450 lb) quantities was tested at distances out to 4.88 m (16 ft) with propagations occurring at all distances.

Guanidine Nitrate. The testing of 9.1 kg (20 lb) quantities at the spacing of 1.14 m (3.8 ft) yielded no propagation occurrences. However, the acceptor containers were destroyed and the explosive strewn about the area. Although the whole area was engulfed in the donor's fireball, none of the strewn explosives burned. The second series of tests on 18.1 kg quantities with a spacing of 1.47 m yielded similar results. And the final series, 36.3-kg quantities with a spacing of 1.68 m also had no propagations occurring.

Conclusions

There was no detonation propagations of 22.7- and 11.3-kg quantities of nitroguanidine at spacings of 2.13 and 1.68 m, respectively. There were definite detonations of 204.1 kg quantities of nitroguanidine at a spacing of 4.88 m. Guanidine nitrate in 9.1-, 18.1-, and 36.3-kg quantities were spaced 1.14, 1.47, and 1.68 m, respectively, without any detonation propagations occurring. However, due to the limited number of tests conducted for all six configurations, no reliable statistical probability of propagation could be calculated.

Critical Depth of TNT (ref 12)

Objective

The objective was to determine if a corrugated rubber conveyor would safely transport bulk flake TNT without propagation of an explosive incident.

Test Specimen

TNT explosive, type 1, flake, placed on a corrugated, serpentix type conveyor at a uniform depth of 38.1 mm (1.5 in.) was used.

Test Arrangement

A series of tests were conducted using an 11-unit length of serpentix conveyor (fig.

14) backed with a 25.4 mm (1 in.) thick wooden plank and supported 381 mm (15 in.) off the ground. The donor was centrally located for maximum effect. The whole conveyor was housed in an aluminum tunnel 0.61 m (2 ft) wide by 0.91 m (3 ft) high, and 2.44 m (8 ft) long (fig. 15). Each of the 11 troughs were filled with 1.25 kg (2.8 lb) of bulk TNT and smoothed to a uniform depth of 38.1 mm (1.5 in.).

Test Results

During the complete test series, there were no detonation propagations observed: therefore, the upper limit of probability of propagation is 7.1% at the 95% confidence level. In all cases, the donor section of the serpentix conveyor was destroyed with minimal damage to the rest of the conveyor. Also, there were a few incidents of the adjacent acceptor troughs (numbers 5 and/or 7) propagating to a low order detonation but never any further.

Conclusion

A 38.1-mm depth of bulk TNT explosive on a 0.61-m wide corrugated (serpentix) rubber conveyor with a definite separation of 25.4 mm between conveyor troughs will prevent the propagation of any explosive incident along the entire conveyor.

Boxes of TNT (ref 7)

Objective

The objective was to establish a safe separation distance between boxes containing kg (55 lb) of TNT on conveyors.

Test Specimen

The standard cardboard shipping container, measuring 476.3 by 387.4 by 193.7 mm (18.8 by 15.3 by 7.6 in.) and containing 24.9 kg of flake, type 1, TNT was used.

Test Arrangements

All tests were conducted within a 0.91 m (3 ft) diameter, hemisphere aluminum tunnel (fig. 16) and with the boxes located 0.46 m (1.5 ft) above the ground on a steel roller conveyor.

Test Results

The tests were conducted at distances ranging from 3.05 to 4.88 m (10 to 16 ft) with the safe separation distance being established at 3.66 (12 ft) and with an upper limit of 6.7%

probability of propagation at the 95% confidence level.

Conclusions

The safe spacing for cardboard boxes containing 24.9 kg of TNT within tunnels was 3.6 m (12 ft).

TNT in Tote Bins (ref 13)

Objective

The objective was to determine the safe separation distance between 76.2 kg (168 lb) quantities of flake TNT contained in aluminum tote bins on a conveyor and within a tunnel.

Test Specimen

Flake TNT (76.2 kg) was used in aluminum tote bins made from 7075-T6 aluminum with a unform thickness of 3.18 mm (0.125 in.), 609.6 mm (24 in.) long by 457.2 m (18 in.) in width and height with a plexiglass hinged lid.

Test Arrangements

Each tote bin was placed on a 1.52 m (5 ft) pedestal to simulate the distance between the conveyor and the tunnel floor. The tote bins were aligned in each test with the front of the bin facing the side of the tunnel (top hinges aligned with the tunnel's axis) and the tops closed.

The first tunnel phase used wooden tunnels that were 2.44 m (8 ft) in both width and height and varied in length from 14.6 to 42.4 m (48 to 139 ft) to full contain all test specimens. The tunnels were assembled from prefabricated modular wall and roof sections, each constructed from wooden beams covered with sheets of wooden paneling 6.35 mm (0.25 in.) thick. The panels were attached to the inside of the frames to insure maximum confinement. The typical wooden tunnel construction is shown in figure 17.

The second phase used metal and fiberglass tunnel (fig. 18) that were the same cross-section as the wooden tunnels, but only varied in length from 12.2 to 18.3 m (40 to 60 ft). The prefabricated modular wall and roof sections were constructed from angle iron covered with corrugated fiberglass panels 0.89 mm (0.035 in.) thick.

Test Results

Tests were conducted using the wooden tunnel configuration with detonation

propagations occurring at 12.8 m (42 ft) or less. Therefore, the safe separation was confirmed at a 15.2 m (50 ft) distance, with an upper limit of 7% probability of propagation at the 95% confidence level.

Tests were conducted using the steel/fiberglass tunnel configuration with detonation propagations occurring at 15.2 m or less. Therefore, the safe separation was confirmed at a 18.3 m distance with an upper limit of 6.9% probability of propagation at the 95% confidence level.

Conclusions

Quantities of flake TNT [76.2 kg (168 lb)] in aluminum (7075-T6) tote bins can be safely transported on conveyors within wooden tunnels, if a distance of 15.2 m or greater is maintained between tote bins. Also, the same explosive filled tote bins can be safely transported within steel and fiberglass tunnels provided a distance of 18.3 or greater is maintained.

MUNITIONS

8-Inch M106 HE Projectile (ref 14)

Objective

The objective was to determine the safe separation distance betwen single 8-inch M106 HE projectiles transported on a conveyor system.

Test Specimen

The 8-inch M106 HE projectile, unfuzed, with the lifting plug, spacer, supplementary charge, and liner removed from the projectile's nose cavity was used. The projectile was loaded with 17.6 kg (38.8 lb) of Composition B and was 798.3 mm (31.4 in.) in length (as tested), with a maximum diameter of 210.3 mm (8.3 in.) at the rotating band. The overall projectile weight varied from 86.8 to 92.7 kg (191.4 to 204.3 lb).

Test Arrangements

The first test phase was an unshielded test array, with the projectiles arranged in a vertical, nose-up position on a pine board (fig. 19). The projectiles were supported 0.76m (2.5 ft) above the existing terrain.

The second test phase used the same basic test array; however, shields were positioned vertically halfway between the projectiles. The shields were solid steel and then aluminum bars 0.76 m in height and of varying diameters.

The third test phase (confirmatory tests) consisted of a shielded test array with aluminum shields.

Test Results

The unshielded tests were conducted at distances ranging from 0.61 to 4.27 m (2 to 14 ft) with either detonation propagations or excessive fragment damage and penetrations occurring at 3.05 m (10 ft) or less. Because this distance was in excess of that compatible with existing facilities, the test phase was cancelled.

The shielded tests were conducted at distances ranging from 0.15 to 1.83 m (0.5 to 6 ft) with the shields always located halfway between the projectiles. Detonation propagations only occurred at the 0.15 m (0.5 ft) distance; however, there was a definite trend of producing greater projectile damage with steel shielding bars than with aluminum. Therefore, a total of 25 confirmatory tests were conducted at a projectile spacing of 0.3 m (1 ft) using aluminum (6061-T6) shielding bars 76.2 mm (3 in.) in diameter and 0.76 m (2.5 ft) long, positioned vertically halfway between the projectiles. This resulted in an upper limit of 6.9% probability of propagation at 95% confidence level.

Conclusions

These projectiles with 76.2 mm (3 in.) diameter aluminum shields and a 0.3 m (1 ft) projectile spacing can be safely transported on conveyor systems.

8-Inch M509 HE Projectile (ref 15)

Objective

The objective was to determine the safe separation distance between 8-inch M509 HE projectiles on their assembly line.

Test Specimen

Single 8-inch M509 HE projectiles contained in a vertical base-up configuration within a prototype crosstransfer pallet system were used. Each projectile contained a total of 180 dual purpose M42 grenades arranged in 12 rows with 15 grenades per row. The projectile's total weight was 93.7 kg (206.5 lb) and contained 5.9 kg (13.1 lb) of Composition A5 within the grenade load. In each case, the nose expelling charge and the base plate were removed.

Test Arrangements

The exploratory phase used two types of prototype transfer pallets: a flat steel plate shield and a "V" shield (fig. 20). The general test array with the transfer pallets welded to the conveyor rails to simulate actual pallet confinement on the LAP line is shown in figure 21.

During the exploratory phase, inert projectiles were used as acceptors with detonation propagations being determined by fragment impacts and penetrations.

The confirmatory phase was conducted using the same general test array with the "V" shielded transfer pallets; however, live projectiles were used for all test positions.

Test Results

The initial configuration used transfer pallets with 25.4 mm (1 inch) thick flat steel shields 1.13 m (3.7 ft) high by 228.6 mm (9 in.) wide, with tests conducted at distances ranging from zero to 1.52 m (5 ft). Since there was sufficient acceptor and pallet damage to indicate the probable propagation of a detonation and the spacing of 1.52 m (5 ft) was the far in excess of LAP compatibility guidelines, the flat shield approach was discontinued.

The next configuration used the "V" shield transfer pallets with all testing being conducted at the 0.82 m (2.7 ft) distance. A total of 3 exploratory (inert acceptors) and 25 confirmatory tests were conducted, resulting in an upper limit of 6.4% probability of propagation at the 95% confidence level.

Conclusion

These projectiles contained within "V" shielded transfer pallets can be positioned with a 0.82 m (2.7 ft) distance. Also, the rigidity of the pallet is sufficient to prevent major grenade spills and the resultants hazard of secondary detonations.

155 mm M107 HE Projectile (refs 16 and 17)

Objective

The objective was to determine the safe spacing for various configurations of 155 mm M107 HE projectiles as transported on conveyors.

Test Specimen

This projectile was a hollow steel shell containing 7 kg (15.4 lb) of Composition B. The projectile weighed 42.2 kg (93 lb) and had an overall length of 607.1 mm (23.9 in.) as tested (without fuze or lifting plug). A secondary test unit consisted of casting pallets containing 24 projectiles in a 4 by 6 matrix with a centerline distance of 177.8 mm (7 in.). Also used with the casting pallets were the loading funnels each with 1.13 kg (2.5 lb) of Composition B, giving each pallet a total explosive weight of 194.9 kg (429.6 lb).

Test Arrangements

The single projectile test array used four basic arrangements: vertical, horizontal, vertical domino, and horizontal domino. The basic layout for both vertical and horizontal domino arrangements is shown in figure 22. A final single projectile test array, using various types of shielding, steel versus aluminum, and plates versus bars, was also conducted (fig. 23). In all single projectile tests, the projectiles were elevated to a height of 0.61 m (2 ft) above the ground.

The casting pallet (24 projectiles) test array (fig. 24) was conducted with and without funnels, also with and without shielding. The whole test array was elevated to a height of 406.4 mm (16 in.) above the ground and oriented so that the short (4 projectile) side of one pallet faced the next one.

Test Results

The initial series of single projectile tests was conducted on vertical oriented rounds at distances ranging from 0.61 to 2.44 m (2 to 8 ft) with propagations occurring out to a distance of 2.13 m (7 ft). Since only four data points were available at the 2.44 m distance, safe spacing was not established. The series of tests with horizontal oriented rounds was conducted at distances from 1.22 to 1.83 m (4 to 6 ft), with propagations occurring out to a distance of 1.52 m (5 ft). Again, due to the limited number of tests at the 1.83 (6 ft) distance, safe spacing was not established.

The next two test series conducted were the vertical and horizontal domino arrays. In both series, only two distances were tried [0.46 and 0.61 m (1.5 and 2 ft)] with degrading propagations in both cases.

The final single projectile test array used various types, sizes, and materials as shields between the projectiles. The only ones with sufficient test data to establish safe separation distances were 12.7 mm (0.5 in.) thick steel (1020) and 25.4 mm (1 in.) thick aluminum (6061-T6) plates, both with a projectile spacing of 0.46 m (1.5 ft). This resulted in an upper limit of 6.9% probability of propagation at the 95% confidence level.

The initial series of pallet tests, without funnels or shields, were conducted at distances ranging from 7.62 to 33.5 m (25 to 110 ft) with propagations occurring out to 27.4 m (90 ft). Therefore, the safe separation distance was established at 33.5 m (110 ft) with an upper limit of 14.7% probability of propagation at the 95% confidence level. The second series of pallet tests, with funnels but without shields, were conducted at distances ranging from 15.2 to 42.7 m (50 to 140 ft) with propagations occurring at all distances. The third and final pallet test series, with funnels and a 19.05 mm (0.75 in.) thick steel (1020) shield, was conducted at distances ranging from 7.62 to 33.5 m with propagations occurring at all distances.

Conclusions

The safe spacing for single projectiles was greater than 2.13 and 1.52m (7 and 5 ft)

for vertical and horizontal orientations, respectively. The close in domino tests, both orientations, indicated a definite degrading of the propagation. The only established safe spacing for single projectiles was 0.46 m (1.5 ft) with either a 12.7 mm (0.5 in.) thick steel (1020) or 25.4 mm (1 in.) thick aluminum plate for a shield.

The safe spacing for pallets of 24 projectiles, in a 4 by 6 matrix, was 33.5 m provided the casting funnels were removed.

155 mm M483 HE Projectile (ref 18)

Objective

The objective was to determine the safe separation distance between 155 mm M483 HE projectiles on their assembly line.

Test Specimen

Single 155 mm HE projectiles contained in a vertical, base-up configuration within simulated transfer pallets were used. Each projectile contained a total of 88 dual purpose grenades (64 M42s followed by 24 M46s) in 11 rows, with 8 grenades per row. The projectile's overall weight is 46.5 kg (102.6 lb) and contains 2.86 kg (6.3 lb) of Composition A5 within the grenade load. In each case, the nose expelling charge and the base plates were removed.

Test Arrangements

The first series of tests used a simulated transfer pallet to hold the projectiles in a vertical position with the whole array suspended 0.46 m (1.5 ft) above the ground (fig. 25).

The second series was conducted using a configuration similar to the first series, except that an empty projectile body, also within a simulated transfer pallet, was positioned as a shield halfway between the live projectiles.

The third series used a shielded prototype transfer pallet (fig. 26) with 25.4 mm (1 in.) thick shields on both sides of the projectile and was contained on an elevated rail system (fig. 27).

Test Results

The separation distances for the first series, unshielded transfer pallets,ranged from 0.91 m (3 ft) to 3.05 m (10 ft) with propagations occurring at all distances tested. As an interim "fix", a second series was conducted using empty shell bodies as shields between the live rounds

with 26 tests being run at a spacing of 0.91 m. While there was no actual propagation of the donor detonation directly to an acceptor projectile, there were numerous cases of grenade spills with individual grenades detonating.

The third series used the prototype transfer pallet with shielding and a zero pallet spacing. A total of 14 tests were conducted without any detonation propagation or major grenade spills. This resulted in an upper limit of 7.4% probability at the 95% confidence level.

Conclusions

The unshielded transfer pallets nonpropagation distance was greater than 3.05 m and the use of empty shell bodies as shields was not an effective deterrent to propagation. The only effective shielding was on the prototype pallet (fig. 26).

155 mm M549 HERA Projectile (ref 19)

Objective

The objective was to determine safe separation distances for various configurations of 155 mm M549 HERA projectiles for use during transportation on continuous feed conveyors.

Test Specimens

The unfuzed 155 mm M549 HERA projectile with its lifting plug, spacer, supplemental charge, and liner was used. This projectile consists of two major energetic components: a warhead assembly with 7.3 kg (16 lb) of Composition B and a solid propellant rocket motor assembly containing 3.17 kg (7 lb) of solid grain propellant. The projectile is 858 mm (33.8 in.) in length (without lifting plug fuze), has a diameter at the rotating band of 158 mm (6.2 in.), and a total weight of 43.5 kg (96 lb).

A second configuration consisted of pallets of eight projectiles with a total weight of 376.5 kg (830 lb) and measuring 0.35 m (1.1 ft) by 0.69 m (2.3 ft) and 0.98 m (3.2 ft) high.

Test Arrangements

The single projectile test array initially used the array shown in figure 28 with the projectiles arranged in a vertical (nose-up) position on a 25.4 mm (1 in.) thick pine board and suspended 0.76 m (2.5 ft) above the existing terrain. A second series of single projectile tests was conducted, using the same test array with the addition of shields located vertically and halfway between the projectiles. The shields were solid aluminum (6061-T6) bars, 76.2 mm (3 in.) in diameter and 0.76 m (2.5 ft) in height.

The palletized projectile test array used eight projectiles in a 2 x 4 matrix with the narrow pallet ends facing each other (fig. 29). Each palletized projectile had a fully loaded casting funnel inserted into its nose cavity. Again, a second series of tests was conducted with shields of various configurations between the pallets.

Test Results

The single projectile, unshielded test array used separation distances ranging from 0.76 to 5.33 m (2.5 to 17.5 ft) with detonation propagations only occurring at the 0.76 m (2.5 ft) distance. Therefore, the safe separation distance was established at 1.52 m (5 ft) with an upper limit of 6.8% probability of propagation at the 95% confidence level. The single projectile, shielded test array used separation distances ranging from 88.9 to 609.6 mm (3.5 to 24 in.) with no propagations occuring. Therefore, the safe separation distance was established at 88.9 mm (3.5 in.) with an upper limit of 6.9% probability of propagation at the 95% confidence level.

The unshielded palletized projectile test array used separation distances ranging from 0.76 to 9.14 m (2.5 to 30 ft) with either propagations or excessive fragment damage occuring at all distances; therefore, no confirmatory tests were conducted. The shielded pallet tests used three shield configurations: two rows of two rods, one row of four rods, and a single plate with separation distances that varied from 0.3 to 3.05 m (1 to 10 ft). Detonation propagations were experienced at distances of 2.13 m (7 ft) and less. The safe separation distance was established at 3.05 m between pallets, using a double row of aluminum (6061-T6) bars 76.2 mm in diameter with the upper limit of 5.6% probability of propagations at the 95% confidence level.

Conclusions

Single 155 mm M549 HERA projectiles without shielding should be spaced 1.52 m on a continuous conveyor. This distance can be reduced to 88.9 mm (3.5 in.) if a shielding rod of aluminum (6061-T6) and 76.2 nm (3 in.) diameter is placed between projectiles.

Pallets of eight projectiles without shielding have propagation potential at distances of 9.14 m; however, using shielding that consists of a double row of the aluminum bars, as used above, the safe separation distance is 3.05 m.

155 mm M795 HE Projectile (ref 20)

Objective

The objective was to determine the safe separation distance between 155 mm M795 HE projectiles on a continuous conveyor.

Test Specimen

Unfuzed 155 mm M795 HE projectiles with the lifting plug removed and a fully loaded casting funnel inserted into the nose cavity were used. The projectile's maximum length was 749.3 mm (29.5 in.) without lifting plug, fuze, or funnel; its overall weight was 45.8 kg (101 lb) and contains 10.7 kg (23.5 lb) of TNT type 1.

Test Arrangements

The test array (fig. 30) used single projectiles oriented in a vertical (nose up) position, and supported on a 25.4 mm (1 in.) pine board 609.6 mm (24 in.) above the terrain.

Test Results

A total of 35 tests were conducted using separation distances ranging from 2.44 to 4.57 m (8 to 15 ft) with propagations occurring at distances of 3.05 m (10 ft) and less. Therefore, the safe spacing distance was established at 4.57 (15 ft) with an upper limit of 7% probability of propagation at the 95% confidence level.

Conclusions

These projectiles may be safely conveyed between operations provided a distance of 4.57 m is maintained between projectiles.

105 mm M1 HE Projectile (ref 21)

Objective

The objective was to determine the minimum nonpropagation spacing between two transport carriages each carrying sixteen 105 mm M1 HE projectiles.

Test Specimen

These HE projectiles were used with their supplementary charges and liners omitted. Also omitted were lifting plugs and fuzes. The projectile was 444.5 m (17.5 in.) in length and weighed 14.4 kg (31.8 lb) with an explosive charge of 2.3 kg (5.1 lb) of Composition B. The complete test specimen used 16 projectiles in a 4 by 4 matrix, resulting in a total carriage explosive weight of 36.8 kg (81.3 lb). Also, there were two conditions with and without riser funnels. The total carriage explosive weight with riser funnel was 55 kg (121.3 lb).

Test Arrangements

The first test sequence used single carriages of 16 projectiles without funnels. One projectile was detonated to determine complete carrier propagation.

The second test sequence was unshielded carriage tests both with and without funnels. The test carriages were supported 0.73 m (2.42 ft) above the ground in a donor and two acceptor array.

The final test sequences were with carriages using the following types of shielding: (1) Four aluminum (6061-T6)bars , 45.7 mm (1.8 in.) in diameter and 0.58 m (1.9 ft) in length, placed on one end of each carriage with the whole test array suspended 0.85 m (2.8 ft) from the ground. In this shielded test array, funnels were not used. (2) Aluminum (6061-T6) plates, 19.05 mm (0.75 in.) thick, attached to the acceptor carriages. The plates were the full width of the carriage and of sufficient height to shield both projectile and funnel. (3) Exactly the same as the second shielded array except that the shielding plates were 1020 steel. In both cases, the complete test arrays were suspended 0.73 m (2.4 ft) from the ground.

Test Results

Only two tests were conducted to determine complete carriage propagation where a single projectile was initiated and in both cases, all items denotated.

In the unshielded carriage tests, either detonation propagations or excessive fragment penetrations were observed at distances up to 12.2 m (40 ft) when funnels were used and 7.62 m (25 ft) when no funnels were present. Sufficient additional tests were conducted on unshielded carriages of projectiles, without funnels, to establish the safe separation distance as 9.14 m (30 ft) with an upper limit of 9.1% probability of propagtion at the 95% confidence level.

In the shielded carriage test sequences the aluminum interrupter bars appeared to be ineffective in preventing numerous fragment penetrations of acceptor projectiles; also, with aluminum plate shielding, detonation propagations were observed at distances out to 4.57 m (15 ft). The steel plate shields were the most effective, with a safe separation distance being established at 6.1 m (20 ft) with an upper limit of 7.1% probability of propagation at the 95% confidence level.

Conclusions

Detontion propagations on unshielded carriages, each with sixteen 105 mm M1 HE projectiles with funnels, were observed at distances of 12.2 m (40 ft). For unshielded carriages of projectiles without funnels, a safe separation distance of 9.14 m (30 ft) was established; and

for carriages with funnels, a distance of 6.1 was established if a 1020 steel plate shield [19.05 mm (0.75 in.) thick] is attached to one end of each carriage.

105 mm M456 HEAT-T Cartridge (ref 22)

Objective

The objective was to determine the safe separation distance for various configurations of fully loaded 105 mm M456 HEAT-T cartridges and their components on conveyors.

Test Specimen

The test specimen represented four stages of assembly of this cartridge and were: (1) cartridge cases with only the M82 primer inserted, (2) cartridge cases with the M82 primer and loaded with 5.7 kg (12.5 lb) of M304A1 propellant, (3) loaded projectiles containing 0.95 kg (2.1 lb) of Composition B, and (4) fully assembled cartridges consisting of projectile plus cartridge case.

Test Arrangements

The first test array used M184 cartridge cases with only the M83 primer installed and positioned vertically (open end up) on a simulated conveyor; however, a preliminary array to check if the primer would rupture its containing case was initially tested.

The second test array was for fully loaded M184 cartridge cases on aluminum transfer pallets on a conveyor. The cartridge cases were positioned vertically (open end up) and suspended 457.2 mm (18 in.) above the ground.

The third test array, for loaded projectiles, had each projectile held in a vertical (nose up) position within its transfer pallet and suspended above the existing terrain at a distance of 457.2 mm.

The fourth test array, for completely assembled M456 cartridges used a transfer pallet that positioned the cartridges vertically (nose and fuze end up) (fig. 31). During the latter part of this test series, an aluminum (6061-T6) bar, 76.2 mm (3 in.) in diameter and 1143.0 mm (45 in.) in height was used as shielding between cartridges.

The fifth test array, again for completely assembled M456 cartridges, used cartridges in a horizontal array (fig. 32). This test array also used an aluminum (6061-T6) car, 76.2 mm in diameter and 1143 mm in height as a shield between cartridges.

Test Results

The first test series, for the M184 cartridge case with a M83 primer, consisted of only five tests in which the primers were functioned normally without rupturing their cartridge case; therefore, the safe separation distance tests for primed cartridge cases was not conducted.

A decision to use the "worst case" spacing for the whole assembly line lead to cancellation of the test series for both M148 cartridge cases and loaded projectiles with the distance for vertically oriented cartridges being used for all three configuration. Therefore, the second test series, for loaded cartridges with a vertical orientation, was conducted at distances ranging from 480.1 to 810.3 mm (18.9 to 31.9 in.) with sufficient damage at all distances to indicate eventual propagation. The second part of this test series used an aluminum bar shield with all tests conducted at the 480.1 mm distance without any observable propagations. Therefore, a safe separation distance for M456 cartridges with shielding was established at 480.1 mm with an upper limit of 6.9% probability of propagation at the 95% confidence level.

The final test series, horizontally oriented with aluminum shielding, was only conducted at a single spacing. Therefore, a safe separation distance was established as 276.9 mm (10.9 in.) with an upper limit of 6.7% probability of propagation at the 95% confidence level.

Conclusions

The M148 cartridge case with only its M83 primer can use zero spacing. The spacing between M456 cartridges with 76.2 mm diameter aluminum (6061-T6) bars for shields was 480.1 mm for vertical orientations and 276.9 mm for horizontal orientations.

81 mm M374A2E1 HE Cartridge (ref 23)

Objective

The objective was to determine a nonpropagation transfer pallet configuration for 81 mm M374A2E1 HE cartridges.

Test Specimen

This cartridge contains a 0.95 kg (2.1 lb) of Composition B within a steel alloy body, a 114.0 g (4.02 oz) propellant charge, an ignition cartridge, and a percussion primer. The cartridges were without fuzes for this program and measured 528.3 mm (20.8 in.) in length with a maximum diameter of 81.3 mm (3.2 in.) and weighed 4.3 kg (9.5 lb).

Test Arrangements

All tests were conducted with th cartridges in a horizontal position on a transfer pallet. The pallet (fig. 33) used aluminum shields 50.8 mm (2 in.) thick and 101.6 mm (4 in.) high between the explosive parts of the cartridge, and plexiglass (lexan) shields 6.35 mm (0.25 in.) thick between the propellant charge sections. The transfer pallet held the cartridges 223.5 mm (8.8 in.) apart and the whole array was suspended on a roller conveyor, 0.91 m (3 ft) above the ground.

Test Results

The aluminum shields were established as effective in previous testing of the 81 mm M374 HE projectile: therefore, only the effectiveness of the plastic shield was being estblished in this test series. Two heights of shielding were tested [101.6 and 152.4 mm (4 and 6 in.)] with propagations occurring at the lower shield height. Therefore, the combination of aluminum and 152.4 mm high plastic shielding was established as preventing propagation on a transfer pallet where the cartridges were spaced 223.5 mm (8.8 in.) apart. This resulted in an upper limit of 8.8% probability of propagations at the 95% confidence level.

Conclusions

A safe spacing for these cartridges was 223.5 mm on a transfer pallet with 50.8 mm thick by 101.6 mm high aluminum (6061-T6) shielding between the explosive components and 6.35 mm thick by 152.4 mm high plastic (lexan) shielding between the propelling charges.

81 mm M374 HE Projectile (ref 23 and 24)

Objective

The objective was to determine the minimum safe separation distance between 81 mm M374 HE projectiles configured in a single and multiunit array.

Test Specimen

The basic unit was the 81 mm M374 HE projectile with its nose liner removed. The projectile is 264.2 mm (10.4 in.) in length and contains 1 kg (2.2 lb) of Composition B. Pallets of 72 projectiles in a 6 by 12 matrix and with a total explosive weight of 70.6 kg (155.7 lb) were also used.

Test Arrangements

The initial single projectile test array used a simulated loading fixture which held the projectiles in a vertical (nose up) position with the whole test array suspended 0.82 m (2.7 ft) above the ground.

The second single projectile test array had the projectiles in a horizontal position on a transfer pallet. This pallet used aluminum (6061-T6) shields [50.8 mm (2 in.) thick and 101.6 mm (4 in.) high] between projectiles and was suspended on a roller conveyor 0.91 m (3 ft) above the ground.

The 72 projectile pallet test array used a multiposition fixture that held the projectiles in a vertical (nose up) position with a spacing between projectiles of 21.08 mm (0.83 in.). The loaded pallets were suspended 0.82 m (2.7 ft) above the ground and were oriented with the six projectile sides facing adjacent pallets.

Test Results

A series of single projectile (vertical orientation) propagation tests were conducted at separation distances ranging from 0.15 to 0.61 m (0.5 to 2 ft), with either propagations, severe penetrations, or pneumatic ruptures occurring at distances of 0.46 m (1.5 ft) or less. Therefore, the safe separation distance was established at 0.61 m with an upper limit of 5.5% probability of propagation at the 95% confidence level.

The second series of single projectile (horizontal orientation) propagation tests, using a transfer pallet, were conducted to determine the effectiveness of the 50.8-mm thick aluminum shielding. Since no propagations occurred at the 223.5 mm (8.8 in.) distance, the upper limit was 4.1% probability of propagation at the 95% confidence level.

The 72-projectile pallet tests were conducted at distances ranging from 1.52 to 12.2 m (5 to 40 ft). While the only propagation occurred at the 1.52-m distance, there was fragment damage and penetrations noted at distances up to 6.1 m (20 ft). Therefore, the safe separation distance for pallets of 72 projectiles was established at 9.14 m (30 ft), with an upper limit of 8.1% probability of propagation at the 95% confidence level.

Conclusions

Single 81 mm M374 HE projectiles in the vertical position may be safely spaced at 0.61 m. The same single projectiles, horizontally oriented on a transfer pallet, may be safely spaced 223.5 mm (8.8 in.) provided an aluminum (6061-T6) shield 50.8 (2 in.) thick is placed between projectiles. The pallets of 72 projectiles can be safely spaced 9.14 m (30 ft) apart.

30 mm XM789 HEDP Projectile (ref 25)

Objective

The objective was to determine the minimum safe separation distances for various assembly configurations of the 30 mm XM789 HEDP projectile.

Test Specimens

Since each configuration was another progressive step in the assembly of the complete projectile, there were four diferent test specimens. (1) Two 13.5 g (0.48 oz) hollow core PBXN-5, type 2, pellets, one stacked vertically on the other, (2) a 30-mm shell body containing the two loose PBXN-5 pellets, (3) a 30 mm loaded body assembly which contained the reconsolidated pellets, a shaped charge liner, and a 0.08 g (0.003 oz) PBXM-5 booster charge, and (4) a complete 30 mm XM789 HEDP projectile with its XM714E6 PD fuze.

Test Arrangements

The first test array, for the two vertically stacked pellets, consisted of a five-unit array on a simulated conveyor suspended 457.2 mm (18 in.) above the ground. Since the acceptor pellets were expected to pulverize, test results were to be based upon witness plates.

The second, third, and fifth test arrays (shell body with loose pellets, loaded body assemblies, and fuzed projectiles, respectively) were exactly the same. In all three cases, the shell body or projectile was positioned vertically (nose up) in a five-unit array on a simulated conveyor.

The fourth test array used loaded body assemblies positioned vertically (nose up) in a five-unit array on a simulated conveyor. The whole test array was positioned inside a disposable oven which heated the test units internally to 96^0C (205^0F).

The sixth test array used fuzed projectiles in a horizontally aligned (nose-to-tail) configuration and heated in a disposable oven to an internal projectile temperature of 96^0C.

Test Results

The first test series, bare PBXN-5 pellets, used spacing ranging from 12.7 to 50.8 mm (0.5 to 2 in.) between the stacked pellets with the only propagations occurring at the 12.7-mm distance. Therefore, the safe separation distance for stacks containing two pellets each was established at 25.4 mm (1 in.) with an upper limit of 6.9% probability of propagation at the 95% confidence level.

The second test series, shell bodies, each containing two loose pellets, used spacings ranging from 12.7 to 50.8 mm between the vertically positioned shell bodies with the only propagations occurring at the 12.7-mm distance. Therefore, the safe separation distance for shell bodies with loose pellets was established at 25.4 mm with an upper limit of 6.7% probability of propagations at the 95% confidence level.

The third test series, loaded body assemblies, used spacings ranging from 12.7 to 25.4 mm with the only propagations occurring at 12.7 mm distance. Therefore, the safe separation distance for loaded body assemblies was established at 25.4 mm with an upper limit of 7.1% probability of propagation at the 95% confidence level.

The fourth test series, loaded body assemblies heated to 96^0F (205^0F), used spacings ranging from 50.8 to 76.2 mm (2 to 3 in.) with the only propagations occurring at the 50.8-mm distance. Therefore, the safe separation distance for heated loaded body assemblied was established at 76.2 mm with an upper limit of 7.1% probability of propagation at the 95% confidence level.

The fifth test series, fuzed projectiles, used spacings ranging from 12.7 to 76.2 mm with propagations occurring up to a distance of 50.8 mm. Therefore, the safe separatiion distance for fuzed projectiles was established at 76.2 mm with an upper limit of 6% probability of propagation at the 95% confidence level.

The sixth test series aligned and heated fuze projectiles, utilized spacings ranging from 76.2 to 381 mm (3 to 15 in.), with propagations occurring at all spacings. Since the 381 mm distance exceeded the maximum allowable for the proposed assembly line, the test series was discontinued.

Conclusion

The safe separation distance for vertical stacks of two PBXN-5 pellets, for vertical shell bodies with loose pellets, and for loaded body assemblies was 25.4 mm; however, for the same loaded body assemblies heated internally to 96^0C, the safe separation distance increased to 76.2 mm. The safe separation distance for vertical 30 mm M789 HEDP projectiles with XM714E6 fuze was 76.2 mm and for the same fuzed projectile positioned horizontally with the shaped charges aligned, the separation was greater than 381 mm.

25 mm XM792 HEI-T Cartridges (ref 26)

Objective

The objective was to determine the safe separation distances of the 25 mm XM792

HEI-T cartridges and their components in various subassembly configurations as they are transported on conveyors.

Test Specimens

Components or completely assembled 25 mm XM792 HEI-T cartridges were used during this test program. These were five distinct test specimens:

1. Stack of three type-I pellets totalling 10.1 g (0.36 oz) of HEI explosive.

2. Single type-II pellet containing 1.94 g (0.07 oz) of HEI explosive.

3. Loaded body assembly containing a reconsolidated 30.2 g (1.07 oz) pellet of HEI explosive.

4. Loaded projectile with a XM715E5 PDSD fuze attached.

5. Complete 25 mm XM792 HEI-T cartridge.

Test Arrangments (fig. 34)

The first test array, for the stack of three type-I pellets, used a five-unit array, each position having a vertical stack of three pellets with a steel witness plate to determine propagations.

The second test array was exactly like the first, including witness plates, except each of the five units were single type-II pellets.

The third test array, for loaded body assemblies, was conducted with the body assemblies in vertical (nose up) position. A five-unit array on a witness plate was used.

The fourth test array, for fuzed projectiles, was conducted with the projectiles in a vertical position with the fuze end up. A five-unit array on a witness plate was used.

The fifth test array, for complete cartridges, was conducted the same as the fourth array.

Test Results

The first test series, stacks of three pellets, was conducted at distances ranging from zero spacing to 76.2 mm (3 in.), with propagations occurring up to a distance of 12.7 mm (0.5 in.). Therefore, the safe separation distance was established as 25.4 mm (1 in.) with an upper

limit of 6.2% probability of propagation at the 95% confidence level.

The second test series, single pellets, was conducted at distances also ranging from zero spacing to 76.2 mm (3 in.), with propagations only occurring at zero spacing. Therefore, the safe separation distance was established as 12.7 mm with an upper limit of 6.9% probability of propagation at the 95% confidence level.

The third test series, loaded body assemblies, was conducted at distances ranging from zero spacing to 76.2 mm with propagations occurring at distances up to 38.1 mm (1.5 in.). Therefore, the safe separation distance was established as 50.8 mm (2 in.) with an upper limit of 7.1% probability of propagation at the 95% confidence level.

The fourth test series, fuzed projectiles, was conducted at distances ranging from 38.1 to 63.5 mm (1.5 to 2.5 in.) with propagations occurring only at the 38.1-mm distance. Therefore, the safe separation distance was established as 50.8 mm with an upper limit of 6.4% probability of propagation at the 95% confidence level.

The fifth test series, complete cartridges, was conducted at distances ranging from zero spacing to 63.5 mm with either propagations or excessive fragment penetrations occurring at distances up to 38.1 mm. Therefore, the safe separation distance was established as 50.8 mm with an upper limit of 6.9% probability of propagation at the 95% confidence level.

Conclusion

The safe spacing between vertical stacks containing three type I pellets was 25.4 mm and between single type II pellets, 12.7 mm. The safe spacing between vertically oriented loaded body assemblies, fuzed projectiles, and complete cartridges was 50.8 mm.

BLU63 A/B Bomblets (ref 10)

Objective

The objective is to determine the nonpropagation distances between various configurations of BLU 63 A/B bomblets and their component parts.

Test Specimen

Two basic test specimens were used: the male and female hemispheres of the bomblet and the complete BLU 63 A/B bomblet. Each hemisphere contains 53.5 g (1.89 oz) of cyclotol and the bomblet contains 106.9 g (3.77 oz).

Test Arrangements

The first test array was an aluminum (6061-T6) pouring tray containing 16 hemispheres with a riser containing an additional 3.4 kg (7.5 lb) of flaked Composition B. Part way through the test series, the riser quantity was reduced to 2 kg (4.4 lb).

The second test array was for hemispheres on a conveyor where the hemispheres are dumped out of their pouring trays onto a transfer conveyor. Therefore, a test array to determine single unshielded spacing between hemispheres was used.

The third test array was for hemispheres in steel-holding fixtures used for drilling and facing operations. The single unshielded conveyor distance was to be determined.

The final test array was for complete bomblets after final assembly. As before, the tests were conducted to determine the minimum safe conveyor spacing.

Test Results

The initial testing of the 16 hemispheres in their aluminum pouring trays used a casting riser with 3.4 kg for Composition B. At separations ranging from 0.49 to 1.01 (1.6 to 3.3 ft), there were no detonation propagations; however, all acceptor hemispheres deflagrated due to fireball initiation of the riser material. By reducing the size of the riser to 2 kg, the separation distance was reduced to zero spacing between trays without any form of propagations. This resulted in an upper limit of 12.6% probability of propagation at the 95% confidence level.

The testing of loose hemispheres on a simulated conveyor was conducted at distances ranging from zero to 152.4 mm (6 in.) with detonations only occurring at the zero spacing. Therefore, the safe separation distance was established as 12.7 mm (0.5 in.) between hemispheres, and resulted in an upper limit of 6.4% probability of propagations at the 95% confidence level.

The testing of single hemispheres in their steel holding fixture used distances ranging from zero to 152.4 mm with the safe spacing being the zero distance and resulting in an upper limit of 7.4% probability of propagation at the 95% confidence level. The zero spacing between steel holding fixtures resulted in a spacing of 12.7mm between the nested hemispheres.

The final testing of assembled bomblets on a simulated conveyor was conducted at distances ranging from 12.7 to 152.4 mm with the only propagations occurring at the 12.7-mm distance. Therefore, the safe separation distance was established at 50.8 mm (2 in.) between BLU 63 A/B bomblets and resulted in an upper limit of 7.1% probability of propagation at the 95% confidence level.

Conclusions

The safe separation distance between aluminum pouring trays containing 16 each BLU 63 A/B bomblet hemispheres was zero spacing provided the excess riser material did not exceed 2 kg. The safe spacing of loose hemispheres on a transfer conveyor was 12.7 mm and the safe spacing of hemispheres in steel holding fixtures was zero. The safe separation of completely assembled BLU 63 A/B bomblets was 50.8 mm.

BLU 97/B Submunition (ref 27)

Objective

The objective was to determine the safe separation distances for various configurations of BLU 97/B submunitions on conveyors.

Test Specimen

The BLU 97/B submunition without fuze (either single units or pallets of 16 units) were used. The basic submunition was a controlled fragmentation steel body with 0.32 kg (0.7 lb) of cyclotol (70/30). The fuze train and zirconium ring were omitted.

Test Arrangements

The first test array consisted of single submunitions separated by an aluminum (6061-T6) shield, 152.4 mm (6 in.) wide by 96.5 mm (3.8 in.) high, and with the upper 30.5 mm (1.2 in.) of the submunition exposed. There were two shield thickenesses used: 19.05 mm (0.75 in.) and 25.4 mm (1 in.).

The second test array, also for single submunitions, used the same basic shield, except it was 152.4 mm high, fully shielding the submunition. Only the 25.4 mm thickness was used.

The third test array was for unshielded pallets containing 16 submunitions each (fig. 35). This test array was positioned on a simulated conveyor and suspended 0.46 m (1.5 ft) above the ground.

The fourth test array, also for pallets of 16 submunitions, required a type of shield that would not block a forced air flow. Two types of shields were used: screens made from number 7 mesh stainless steel wire belting, and a 12.7 mm (0.5 in.) thick aluminum plate cut in an open "picket fence" design with a second layer's spaces covered by the first layer's columns.

The fifth test array, again for pallets of 16 submunitions, used a solid aluminum (6061-T6) shield 12.7 mm (0.5 in.) thick by 203.2 mm (8 in.) high and 406.7 mm (16 in.) wide.

Test Results

The first test series, for partially shielded single submunitions, was conducted at distances ranging from zero spacing to 228.6 mm (9 in.) and with two shield thicknesses. Propagations were observed on all tests using the 19.05 mm (0.75 in.) thickness and with the 25.4 mm thickness at distances up to 127 mm (5 in.). Therefore, the safe separation distance was established at 228.6 mm (9 in.) using a 25.4 mm (1 in.) thick aluminum shield. This resulted in an upper limit of 6.9% probability of propagation at the 95% confidence level.

The second test series, for fully shielded single submunitions, had only a few tests conducted. The safe separation for the fully shielded submunitions and the shield thickness were the same as the first test series; therefore, the established distance and related probability of propagation are the same.

The third test series, for unshielded pallets, was conducted at distances ranging from 0.91 to 6.1 m (3 to 20 ft) with propagations of excessive fragment damage occurring at distances up to 4.57 m (15 ft). Since this distance was no compatible with planned line layouts, the test series was discontinued.

The fourth test series, pallets with "air flow" shielding, was conducted initially with a wire mesh type of shield, in single and multiple layers, up to a 1.52 m (5 ft) distance (maximum acceptable) without valid results. The revised shielding, the picket fence design, was used in a series of tests at distances ranging from 0.61 to 1.52 m (2 to 5 ft) with excessive fragment damage occurring at distances up to 1.22 m (4 ft). Therefore, the safe separation distance was established at 1.52 m with an upper limit of 7% probability of propagation at the 95% confidence level.

The fifth test series, for pallets with solid shields, was conducted at distances ranging from 0.61 to 1.22 m with sufficient fragment penetrations occurring at the 0.61 m (2 ft) distance. Therefore, the safe separation distance was established at 1.22 m with an upper limit of 6.9% probability of propagation at the 95% confidence level.

Conclusions

The safe spacing for single BLU 97/B submunitions on a conveyor, with either full height or 75% height shields of 25.4 mm (1 in.) thick 6061-T6 aluminum was 228.6 mm (9 in.). The safe spacing between pallets, each containing 16 submunitions and using an air-flow barrier of two layers of 12.7-mm thick 6061-T6 aluminum plates cut in an open "picket fence" design

with a second layer's spaces covered by the first layers columns, was 1.52 m. The safe spacing between the same pallets with a solid 12.7-mm thick 6061-T6 aluminum shield was reduced to 1.22 m. Also, the safe spacing for unshielded pallets was greater than 4.57 m (15 ft).

M42 and M46 GP Grenades (refs 28 and 29)

Objective

The objective was to determine the minimum safe separation between M42 and M46 GP grenades in various assembly and loading configurations.

Test Specimen

Since the M42 and M46 GP grenades are similar in design and explosive content, only the M42 was tested. The grenades basic dimensions were 63.5 mm (2.5 in.) in length with a maximum diameter of 38.1 mm (1.5 in.) and contained 30 g (1.06 oz) of Composition A5. All testing was conducted on the M42 GP grenade without its M223 fuze.

Test Arrangments

There were a total of six basic test arrays used, representing various grenade and grenade-to-projectile assembly locations.

The initial test array was basic grenades spaced on a simulated conveyor and suspended 0.76 (2.5 ft) from the ground. A five pattern array was used with the grenades oriented vertically and shaped charge facing down (fig. 36)

The second test array used polpropylene trays containing 64 grenades in an 8 by 8 matrix within slotted compartments. The trays were positioned on a simulated conveyor and suspended 0.76 m from the ground.

The third test array used aluminum carriers, each with six shelves containing two trays each (768 grenades per carrier), suspended from a simulated pendant conveyor within an aluminum sided and roofed tunnel (fig. 37).

The fourth test array was for a grenade cluster tray (fig. 38) that was a vacuum formed ABS plastic tray containing 32 grenades arranged in four rings of 8 grenades with two central cavities for spare parts. Both single- and double-cluster trays were to be tested with the double tray being two single ones joined by a set of locking pins.

The last two test arrays were basically the same with two different ring packs of

grenades. The ring packs contain either 8 grenades (for 155-mm projectiles) or 15 grenades (for 8-inch projectiles). The basic test array (fig. 39) was suspended 457.2 mm (18 in.) above the ground.

Test Results

For the single grenade test series, the grenade spacing ranged from zero to a maximum of 381 mm (15 in.), with either detonations occurring or excessive fragment penetrations at 25.4 mm (1 in.) or less. Therefore, the safe separation distance was established at 50.8 mm (2 in.) with an upper limit of 6.4% probability of propagation at the 95% confidence level.

The second test series, trays of 64 grenades, was conducted at distances ranging from 0.15 to 2.13 m (0.5 to 7 ft), with propagations occurring at 1.52 m (5 ft) and less. Tests at 1.83 m (6 ft) evidenced excessive fragment penetrations; therefore, the safe separation distance was established at 2.13 m (7 ft) and resulted in an upper limit of 7.4% probability of propagation at the 95% confidence level.

The third test series, 12 trays on a pendant conveyor within an aluminum tunnel, was conducted at distances ranging from 6.1 to 15.2 m (20 to 50 ft). Since there was excessive fragment penetrations at 9.14 m (30 ft) distance, the safe separation distance was established at 12.2 m (40 ft) with an upper limit of 8.8% probability of propagation at the 95% confidence level.

The fourth test series was the cluster trays of 32 grenades in four circular clusters. A series of ignition tests were conducted where one cluster of 8 grenades was initiated without propagation to the other cluster within the same tray or those in the next tray. It was concluded that zero spacing between trays would not yield any propagations. With the zero spacing, sufficient tests were conducted to result in an upper limit of 5.7% probability of propagation at the 95% confidence level.

The fifth test series, an eight grenade ring pack on a conveyor, was conducted at distances ranging from 152.4 to 609.6 mm (6 to 24 in.) with propagations occurring up to spacing of 228.6 mm (9 in.). Therefore, the safe separation distance was established at 304.8 mm (12 in.) and resulted in an upper limit of 6.7% probability of propagation at the 95% confidence level.

The final test series, a 15-grenade ring pack on a conveyor, was conducted at distances ranging from 304.8 to 457.2 mm (12 to 18 in.). While no direct propagations occurred, there was sufficient fragment penetrations at the 304.8-mm distance to indicate eventual propagation. Therefore, the safe separation distance was etablished at 457.2 mm and resulted in an upper limit of 14% probability of propagation at the 95% confidence level.

Conclusions

Separate testing of M46 GP grenades was unnecessary because of simularities of design and explosive content to the M42 GP grenades. The safe separation distance for single M42 GP grenades was 50.8 (2 in.); for square trays of 64 grenades, 2.13 (7 ft); and for 12 trays on a pendant conveyor within an aluminum tunnel (768 grenades), 12.2 m (40 ft). The safe spacing between single- or dual-cluster trays (32 or 64 grenades, respectively) was zero in both cases. The safe spacing between 8 grenade ring packs (for 155m M483 HE projectile) was 304.8 mm and between 15 grenade ring packs (for 8 in. M509 HE projectile) was 457.2 mm.

M56 Mine (ref 30)

Objective

The objective was to determine the safe separation distance for two configurations of M56 mines as encountered during their assembly process.

Test Specimen

The individual M56 mines contain 1.36 kg (3 lb) of composition H6, and are configured individually and two to a dispensing canister.

Test Arrangements

Two test arrays were used, both with the same basic setup (fig. 40), one for the single mines and the second for the canister assemblies. The mines, in both cases, were aligned with the same orientation as on their assembly line (fuze wells to the right; ejection charges to the left).

Test Results

The individual mine test series was conducted at a spacing of 152.4 mm (6 in.) with only minor damage to the acceptor units. Therefore, the safe separation distance for single M56 mines was established at 152.4 mm with an upper limit of 7.1% probability of propagation at the 95% confidence level. This same separation distance was used and established for the canister assemblies containing two mines.

Conclusions

A safe spacing for either individual or canisters containing two M56 mines was 152.4 mm.

M74AP and M75AT-AV Mines (ref 31)

Objective

The objective was to determine the safe separation distance between M74AP or M75AT-AV mines on a conveyor.

Test Specimen

The complete mine consists of a charge case assembly with 0.59 kg (1.3 lb) of RDX explosive, two conical-shaped charge plates, two cover plates, a S/A mechanism, a booster charge, an electronics assembly, and an electric battery primer. To reduce materials costs, the electronic and S/A mechanism was omitted from the test specimens.

Test Arrangments

The initial test array used three modified mines on a simulated conveyor and supported 304.8 mm (12 in.) above the ground (fig. 41). After the initial unshielded test array, a series of two types of shielding was tested, both located halfway between the mines: (1) a 76.2 mm (3 in.) diameter 6061-T6 aluminum bar cut to the full height of the mine, (2) an aluminum (6061-T6) brick, 76.2mm square, and cut to the full width for the simulated conveyor, 304.8 mm (12 in.).

Test Results

The unshielded test series was conducted at distances ranging from 0.46 to 5.94 m (1.5 to 19.5 ft) with propagations occurring up to distances of 2.59 m (8.5 ft). Since this distance was incompatible with planned layouts and production rates, a second test series using shields of aluminum bars was conducted. Distances during this test series ranged from 0.076 to 1.37 m (0.25 to 4.5 ft) without any propagations occurring. Therefore, the safe separation distance was established as 76.2 mm between mines with a 76.2-mm thick shield. This resulted in an upper limit of 11.3% probability of propagation at the 95% confidence level. A final series of tests was conducted to prove a 76.2-mm square shield without any propagations occurring.

Conclusions

Unshielded M74AP or M75AT-AV mines on a conveyor propagated at distances up to 2.59 m. The safe separation distance between mines was 76.2 mm provided a shield at least 76.2-mm thick was located between the mines.

REFERENCES

1. Stirrat, W.M., "Minimum Nonpropagation Distance of Open Rubber Buckets Containing Explosive Composition A5," Technical Report ARLCD-TR-78045, ARRADCOM, Dover, NJ, August 1978.

2. Stirrat, W.M. and Rindner, R.M., "Determinations of Minimum Nonpropagation Distance of Aluminum Buckets Containing 15 Pounds of Composition A5," Technical Report ARLCD-TR-78006, ARRADCOM, Dover, NJ, February 1978.

3. Seals, W., Kukuvka, R.S. and Sarrett, H., "Safe Separation Tests of Composition A7 Explosive in 165 Pound Tote Bins, Interim Report," Technical Memorandum 2189, ARRADCOM, Dover, NJ, October 1975.

4. Wenzel, A.B. and Rindner, R.M., "The Effects of Shielded Tote Bins on the Safe Separation of 168 Pounds of Composition A7 Explosive," Contractor Report ARLCD-CR-77012, ARRADCOM, Dover, NJ, September 1977.

5. Kukuvka, R.S. and Gandhi, K.A., "Critical Depth Test of Composition B Flake," Technical Report 5014, ARRADCOM, Dover, NJ, November 1976.

6. Stirrat, W.M., "Determination of Minimum Nonpropagation Distance Between Segments of 105 mm M1 Projectile Composition B Riser Scrap," Technical Report ARLCD-TR-78022, ARRADCOM, Dover, NJ, April 1978.

7. Kukuvka, R.S. and Gandhi, K.A., "Propagation Tests of 55 Pound Boxes of Bulk TNT and 60 Pound Boxes of Bulk Composition B," Technical Report 4622, Picatinny Arsenal, Dover, NJ, December 1973.

8. Kukuvka, R.S. and Sarrette , H., "Separation Distance Tests of 60 Pound Buckets of Composition B in Metal Ramps," Technical Report 4759, ARRADCOM, Dover, NJ, April 1975.

9. Kukuvka, R.S. and Sarretee, H., "Separation Distance Tests of 35 and 50 Pound Aluminum Buckets of Composition C4 in Metal Ramps," Technical Report 4760, ARRADCOM, Dover, NJ April 1975.

10. Slater, F.E., Bergmann, E.P., Seals, W.O., and Rindner, R.M., "Development of Safe Separation Criteria for the Manufacture of BLU Bomblets," Contractor Report ARLCD-CR-80007, ARRADCOM, Dover, NJ, June 1980.

11. Templeton, B.A., Letter Report, "Transmittal of Data Sheets for Nitroguanidine and Guanidine Nitrate Tests," ARRADCOM, Dover, NJ, March 1980.

12. Stirrat, W.M. and Rindner, R.M., "Critical Depth Tests of Bulk TNT Flake Explosives," Technical Report ARLCD-TR-78003, ARRADCOM, Dover, NJ, January 1978.

13. Stirrat, W.M., "Minimum Nonpropagation Distance for 76.2 kg (168 lb) of Flake TNT in Interconnecting Building Ramps," Technical Report ARLCD-TR-79018, ARRADCOM, Dover, NJ, November 1979.

14. Stirrat, W.M., "Determination of Minimum Nonpropagation Distance of 8 Inch M106 HE Projectiles," Technical Report ARLCD-TR-79014, ARRADCOM, Dover, NJ, June 1979.

15. Stirrat, W.M. and Rindner, R.M., "Minimum Nonpropagtion Distance for 8 Inch M509 HE Projectiles," Technical Report ARLCD-TR-81005, ARRADCOM, Dover, NJ, April 1981.

16. Anderson, C. and Rindner, R.M., "Separation Distance Test of 155 mm (M107) Projectiles," Technical Report 4425, ARRADCOM, Dover, NJ, January 1973.

17. Kukuvka, R.S. and Kossover, O., "Determination of Minimum Nonpropagation Distance of 155 mm M107 Projectile Grouped 24 on a Pallet," Technical Report 5008, ARRADCOM, Dover, NJ, September 1976.

18. Stirrat, W.M., "Minimum Nonpropagation Distance for 155 mm M483 HE Projectiles," Technical Reports ARLCD-TR-81004, ARRADCOM, Dover, NJ, March 1981.

19. Stirrat, W.M., "Determination of Minimum Nonpropagation Distances of Various Configurations of 155mm M549 HERA Projectiles", Technical Report ARLCD-TR-81023, ARRADCOM, Dover, NJ, April 1981.

20. Stirrat, W.M., "Determination of Minimum Nonpropagation Distance for 155 mm M795 HE Projectile," Technical Report ARLCD-TR-81024, ARRADCOM, Dover,NJ, April 1981.

21. Kukuvka, R.S. and Sarrett, H., "Determination of Minimum Nonpropagation Distance of 105 M1 Projectiles Grouped 16 on a Pallet," Technical Report 4869, ARRADCOM, Dover, NJ, Septemer 1975.

22. Stirrat, W.M., "Determination of Nonpropagation Distances for 105 mm M456 HEAT-T Cartridges," Technical Report ARLCD-TR-81013, ARRADCOM, Dover, NJ, July 1981.

23. Anderson, O. and Stevens, R., "Eight Inch Separation Propagation Tests for Cartridge 81 mm HE M374A2E1 and Projectile 81 mm HE M374," Technical Report 4773, ARRADCOM, Dover, NJ, June 1975.

24. Koger, D.M. and Stirrat, W.M., "Determination of Minimum Nonpropagation Distance of 81 mm M374A1 Projectiles," Technical Report ARLCD-TR-78021, ARRADCOM, Dover, NJ, April 1978.

25. Stirrat, W.M. and Rindner, R.M., "Minimum Nonpropagation Distances for Various LAP Facility Configurations of the 30 mm XM789 HEDP Projectiles," Technical Report ARLCD-TR-82029, ARRADCOM, Dover, NJ, January 1983.

26. Stirrat, W.M., "Determination of Nonpropagation Distances for 25 mm XM792 HEI-T Cartridges," Technical Report ARLCD-TR-83002, ARRADCOM, Dover, NJ, February 1983.

27. Stirrat, W.M., "Minimum Nonpropagation Criteria for Load, Assemble, and Pack (LAP) Facilities for the BLU-97/B Submunition," Technical Report ARLCD-TR-84024, ARRADCOM, Dover, NJ, March 1985.

28. Stirrat, W.M. and Rindner, R.M., "Determination of Minimum Nonpropagation Distance of M42 and M46 Grenades Without Fuze," Technical Report ARLCD-TR-78004, ARRADCOM, Dover, NJ, February 1978.

29. Stirrat, W.M., "Minimum Nonpropagation Distances for M42/M46 GP Grenade Loading Tools," Technical Report ARLCD-TR-83016, ARRADCOM, Dover, NJ, March 1983.

30. Smith, A.L., "Explosive In-Plant Safe Separation and Sensitivity Criteria," Test Report AMC Project 5764288, Thiokol, July 1976.

31. Stirrat, W.M., "Determination of Nonpropagation Distance for M74AP and M75ATAV Mines," Technical Report ARLCD-TR-83027, ARRADCOM, Dover, NJ, May 1983.

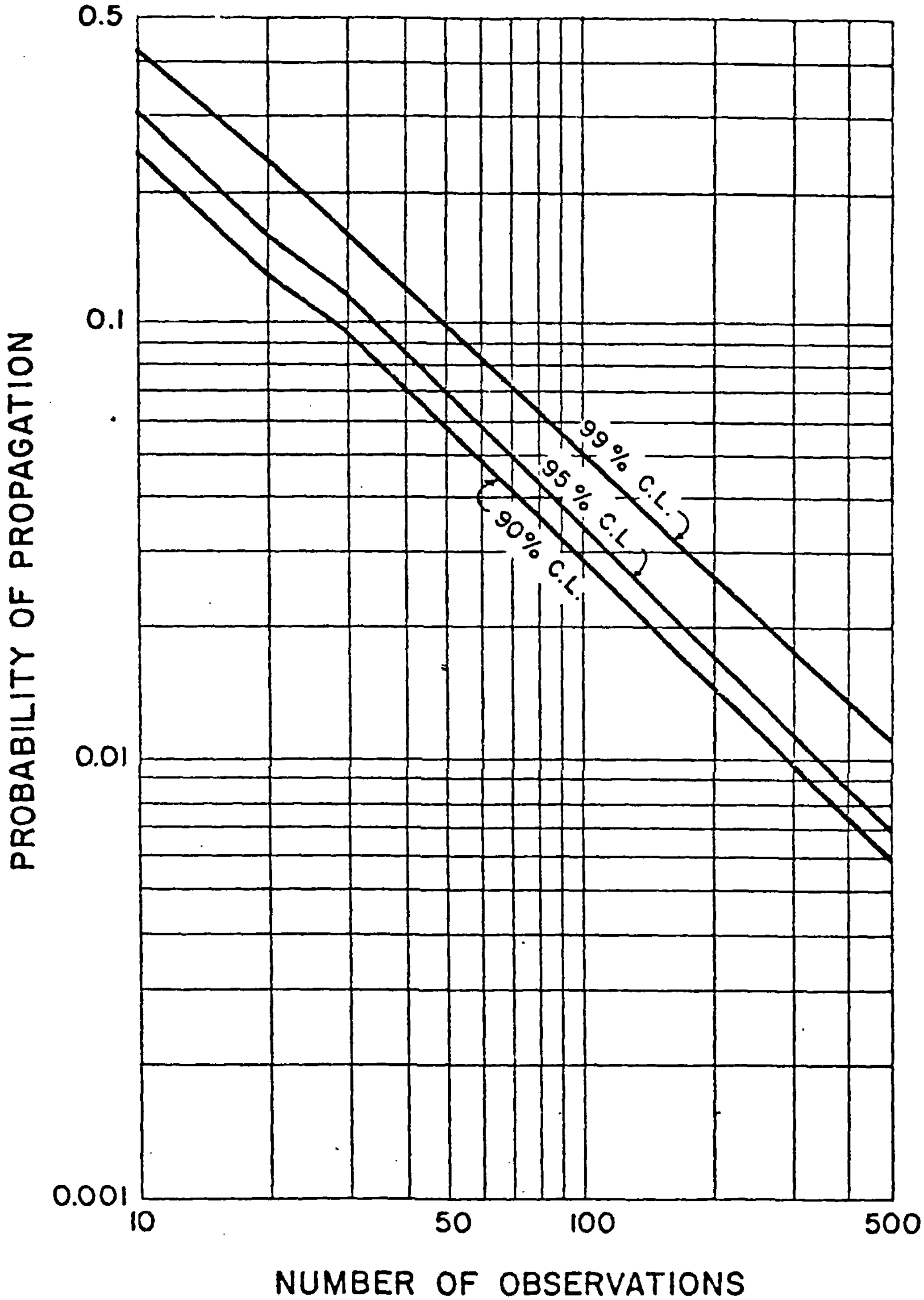

Figure 1. Propagation probability versus number of observations

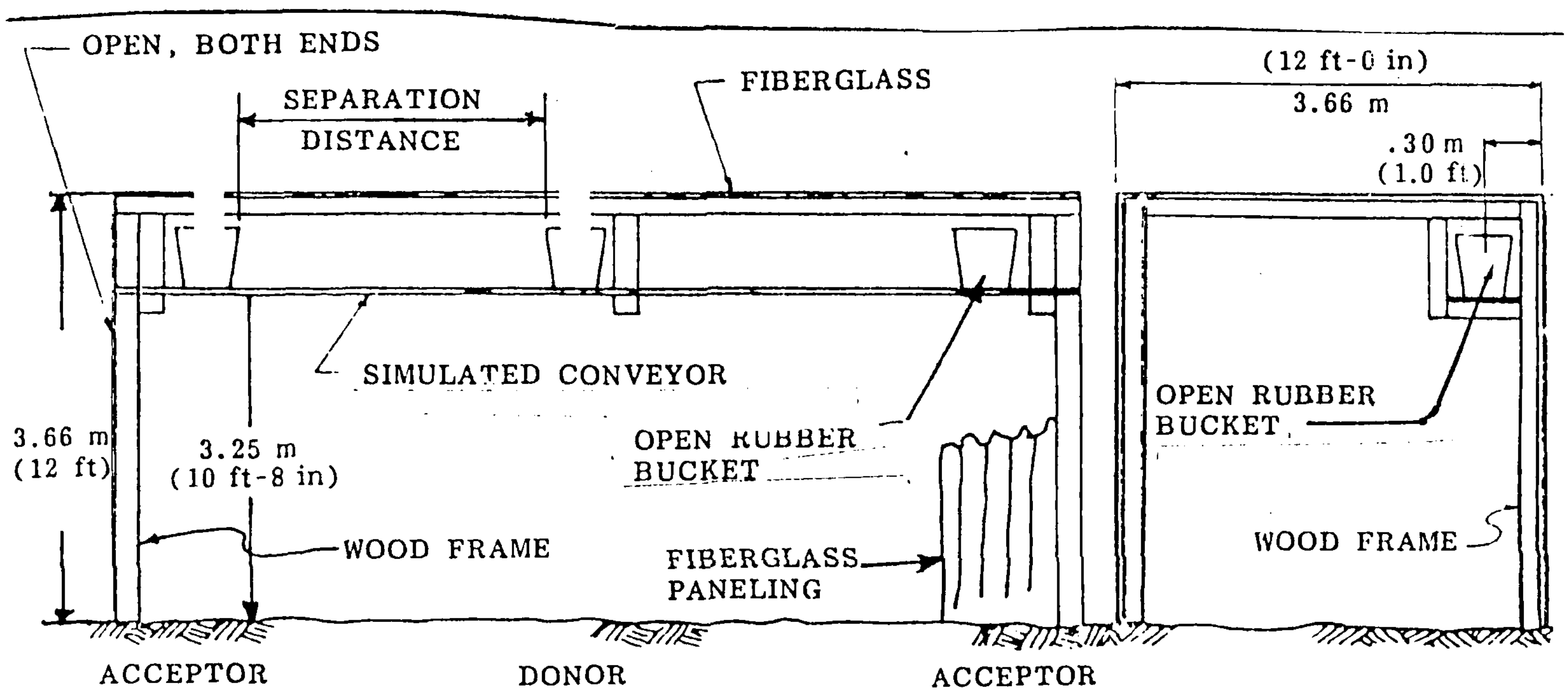

Figure 2. Setup for rubber buckets

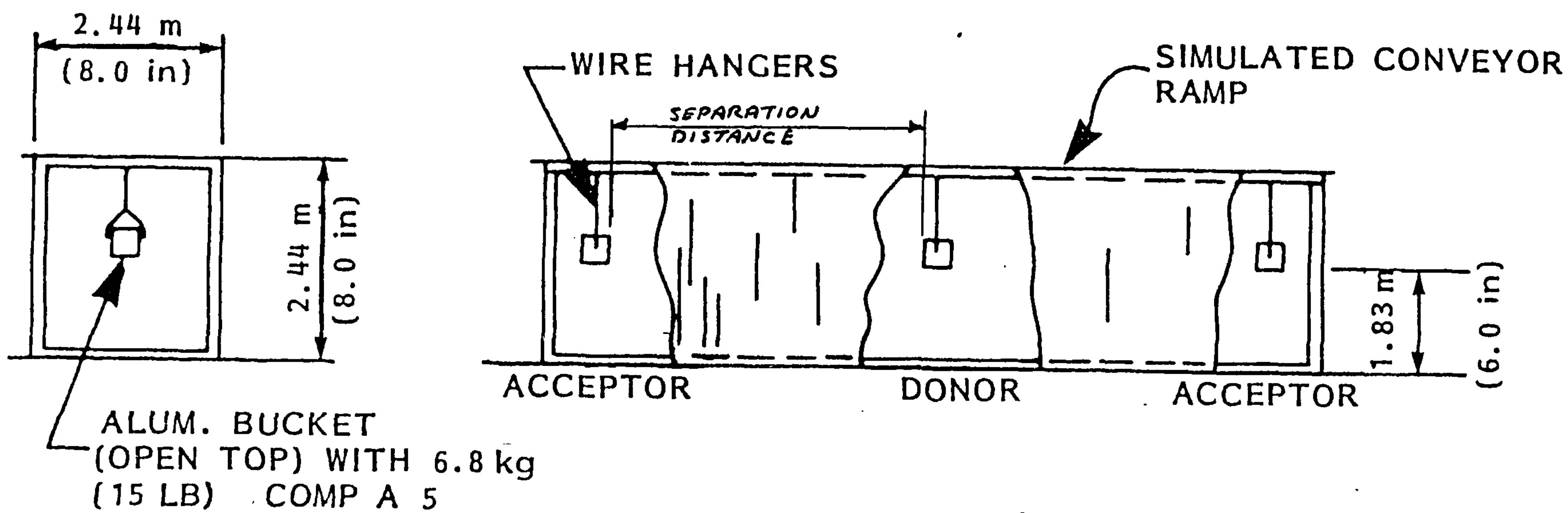

Figure 3. Setup for aluminum buckets

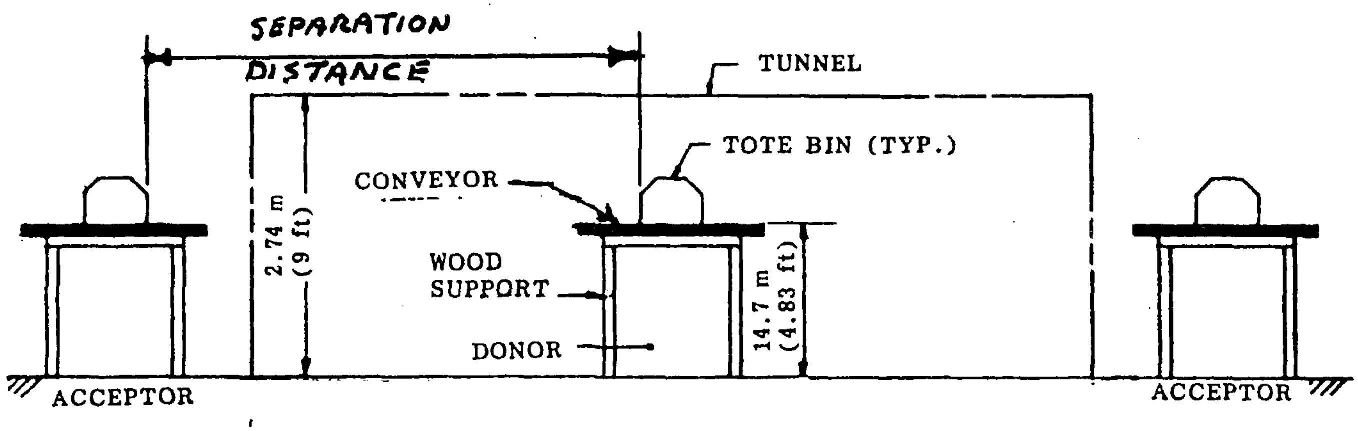

Figure 4. Tote bin arrangement

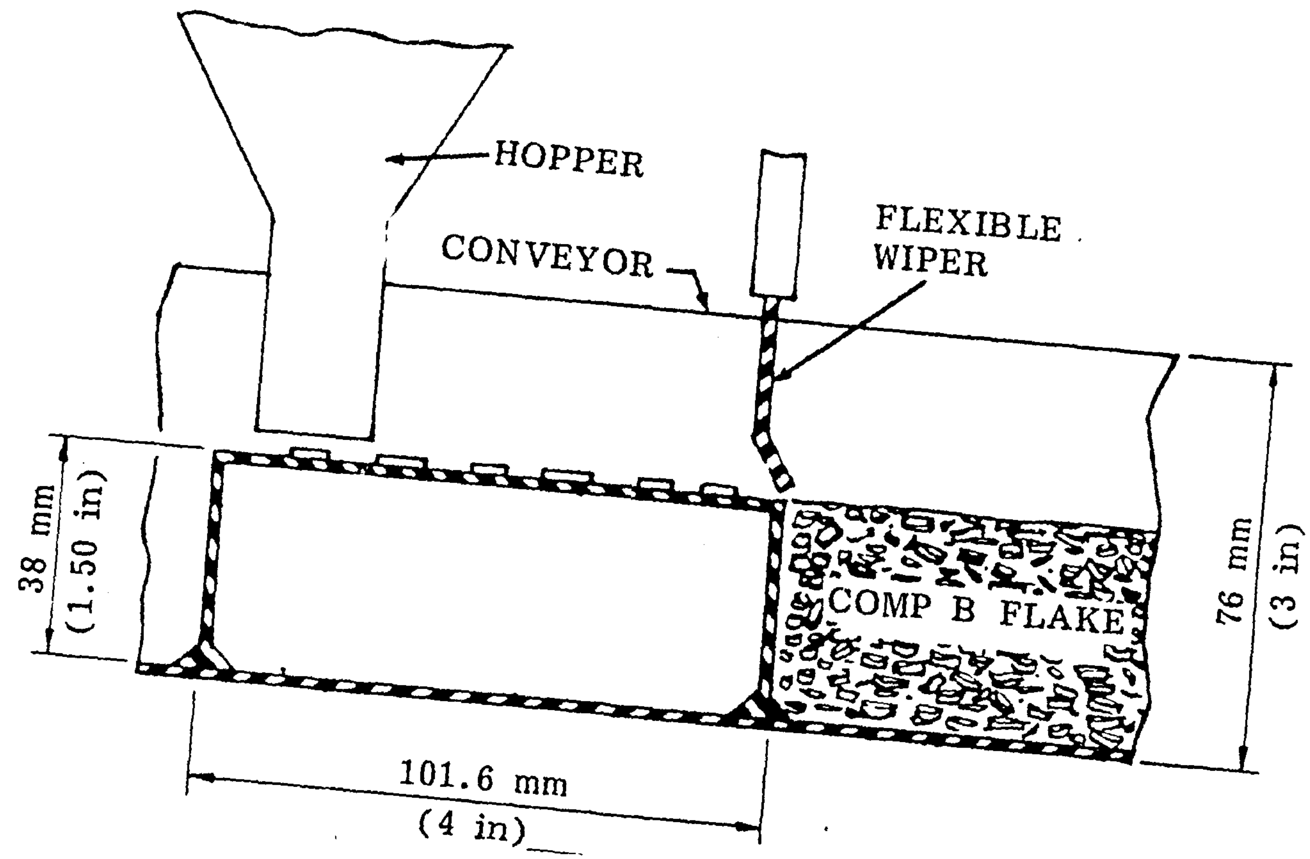

Figure 5. Square airgap

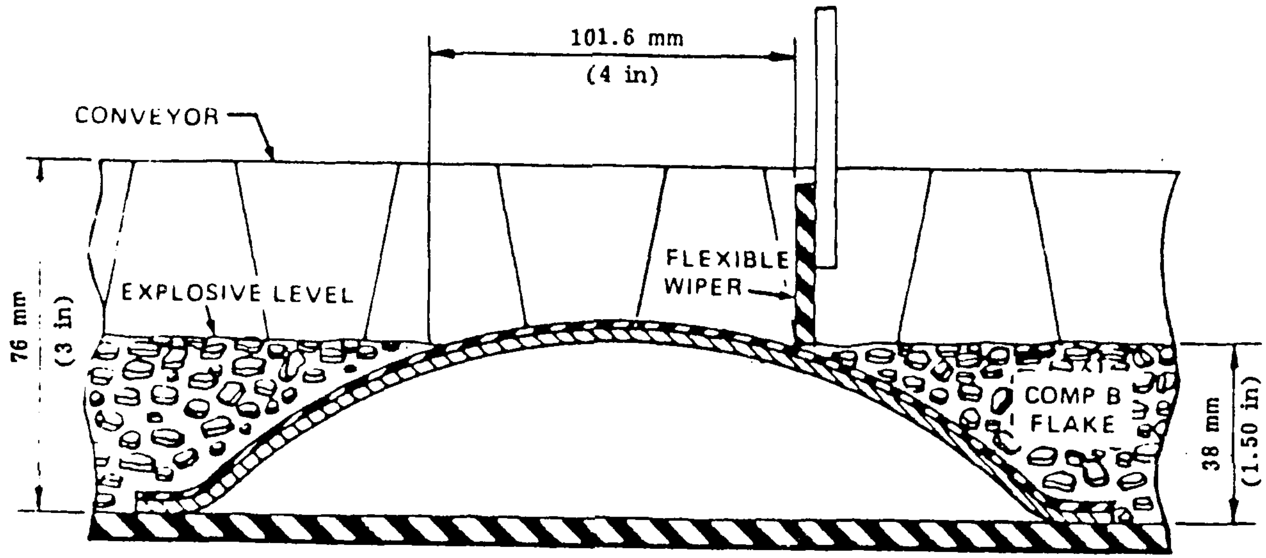

Figure 6. Round air gap

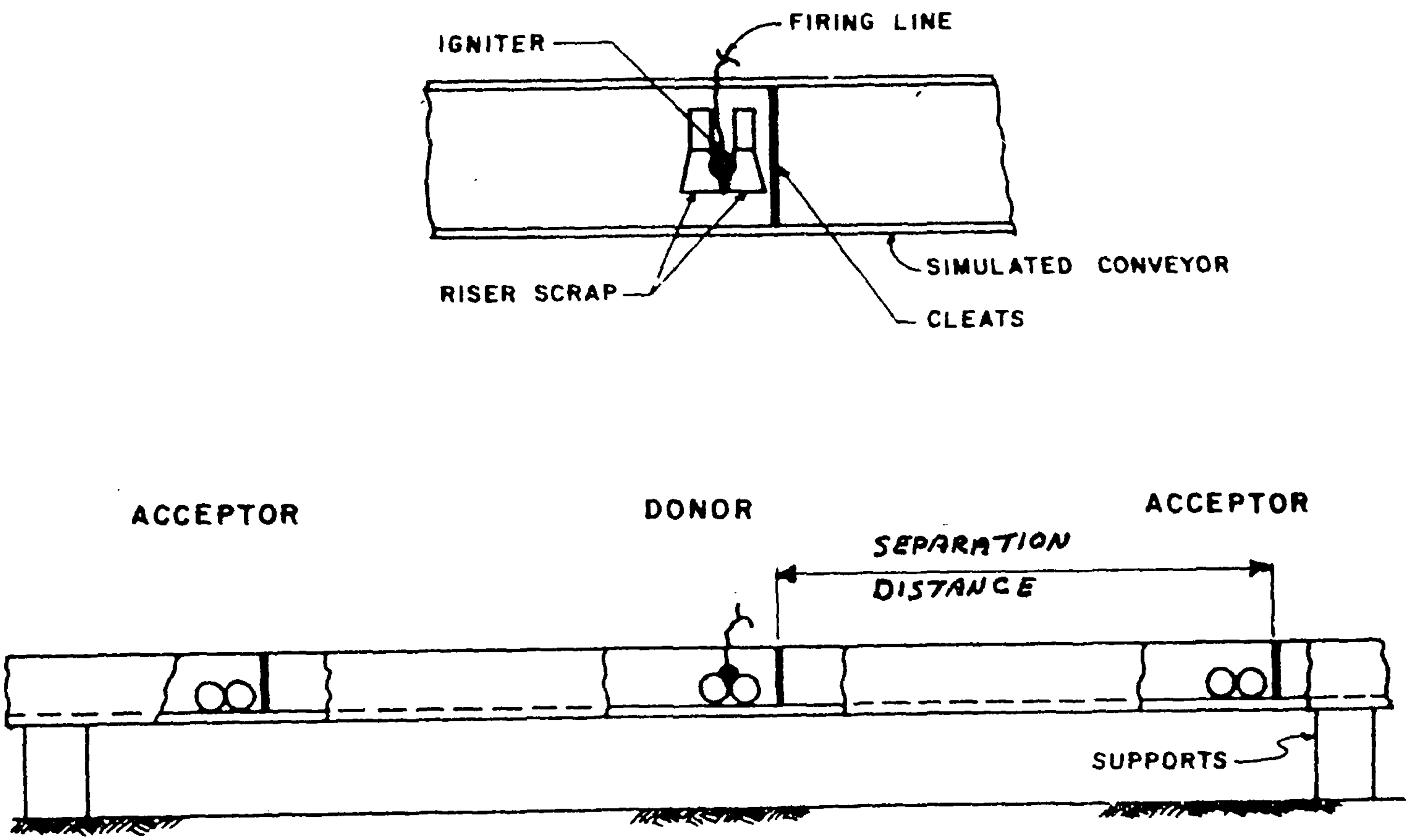

Figure 7. Setup for conveyor riser scrap

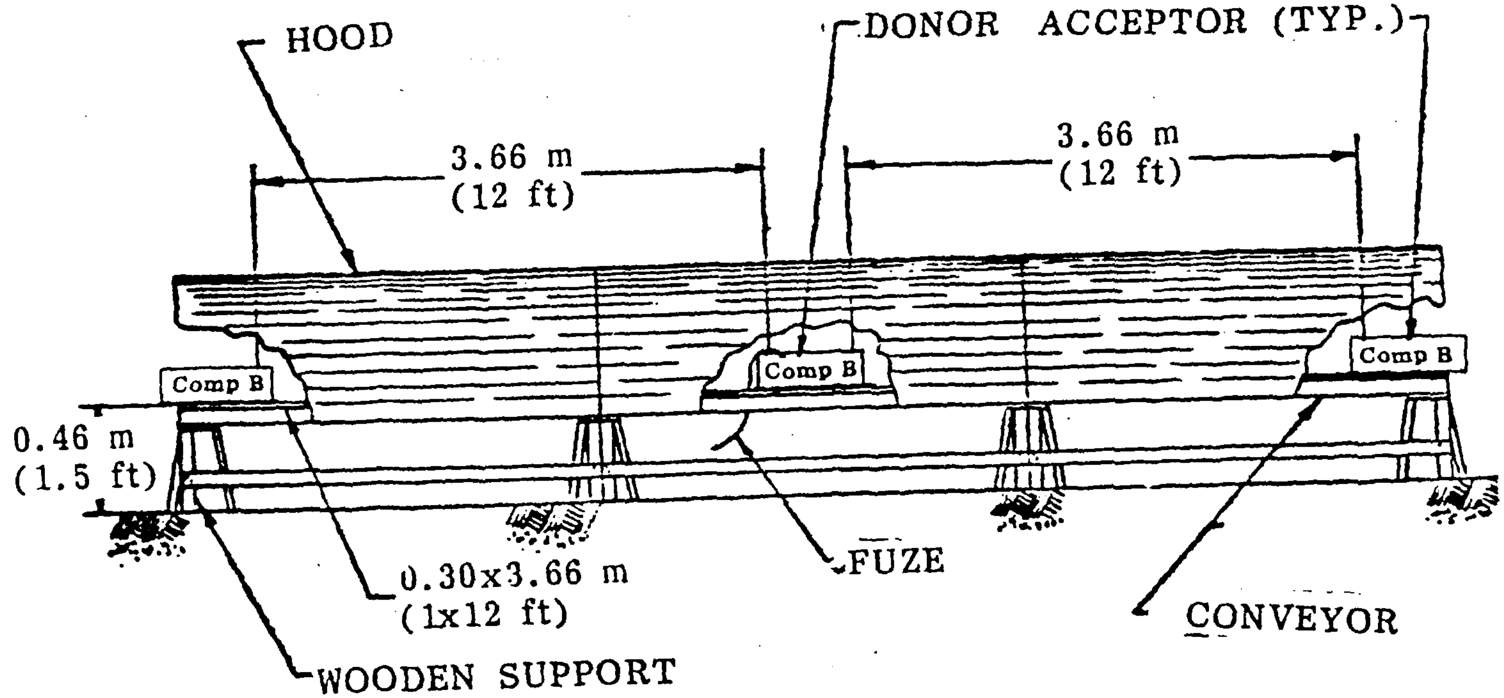

Figure 8. Setup for bulk Composition B

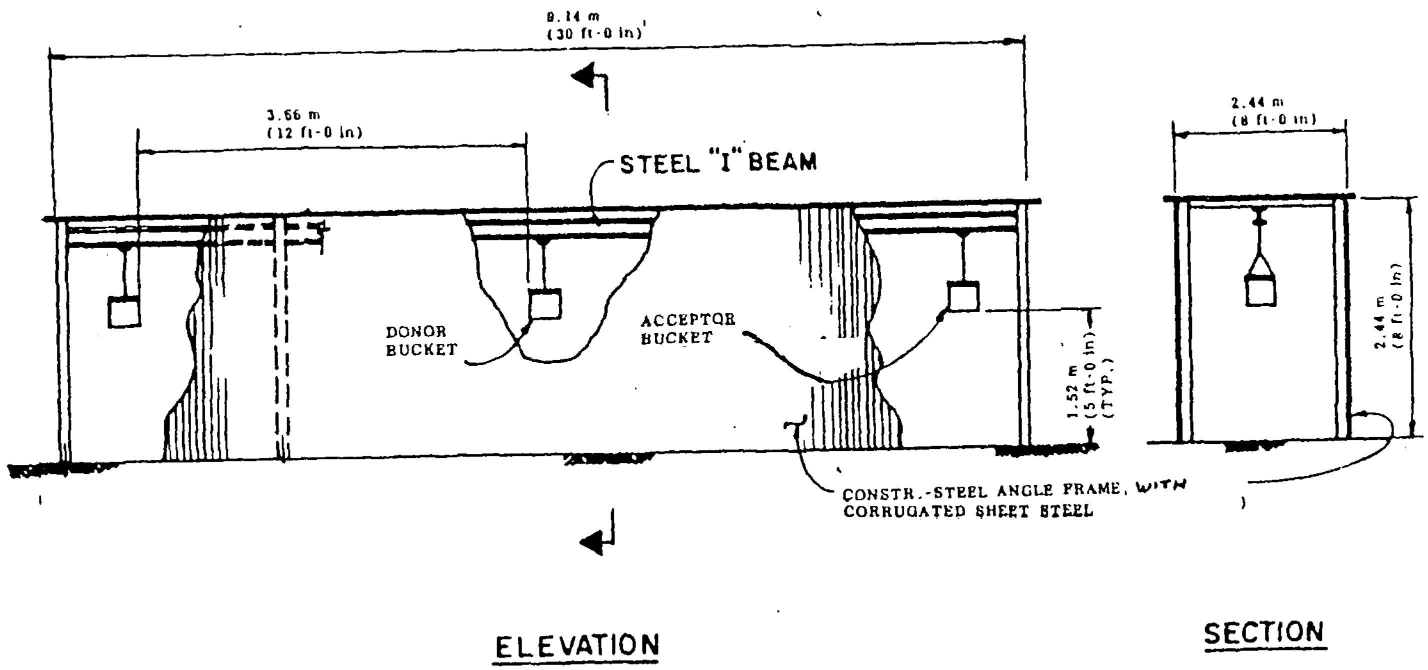

Figure 9. Setup for buckets of Composition B

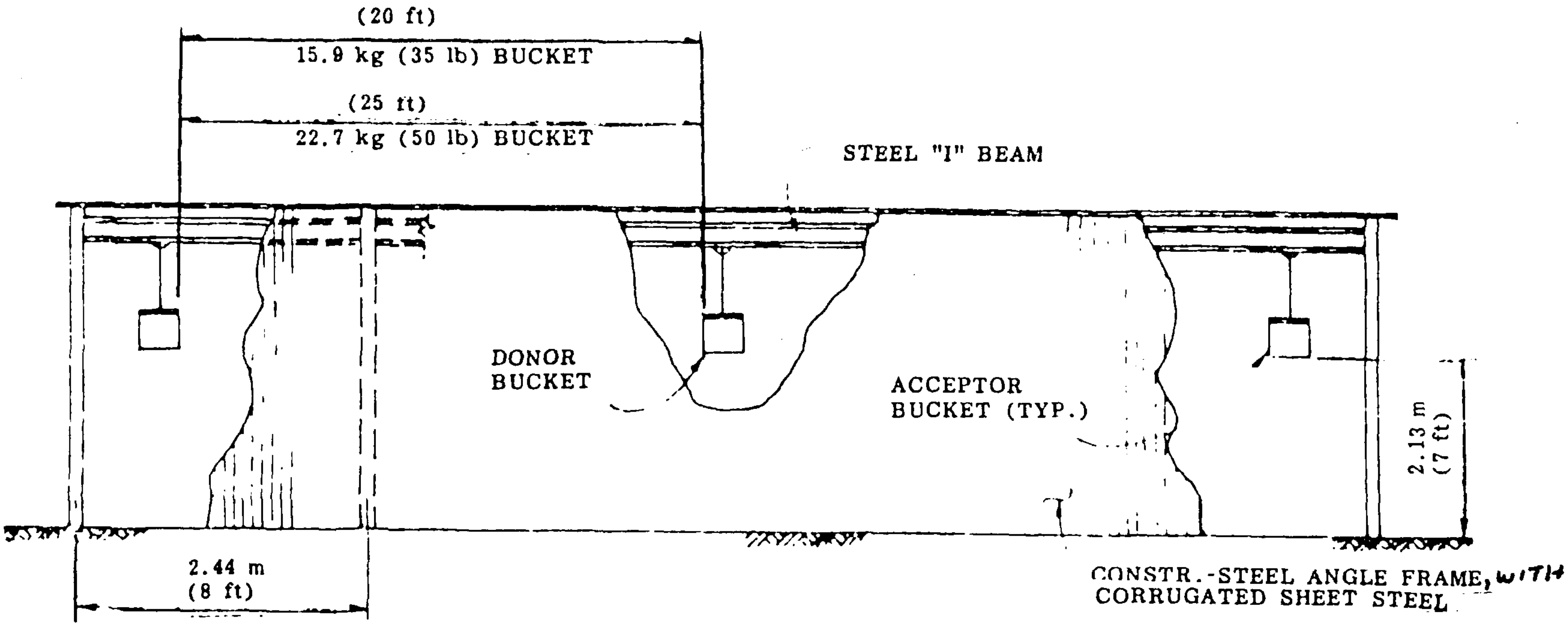

Figure 10. Setup for buckets of Composition C4

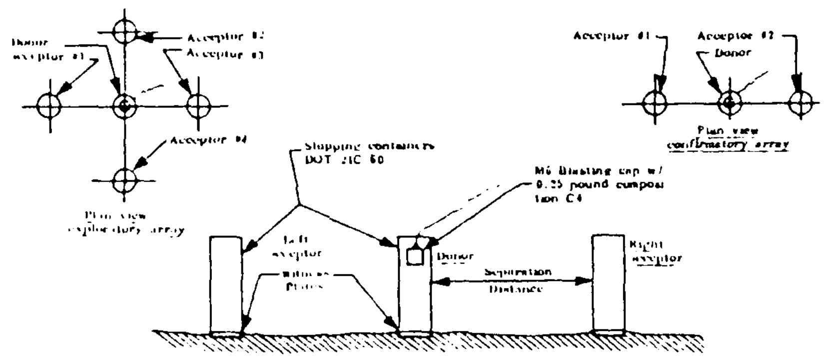

Figure 11. Nitroguanidine (22.7 kg) and guanidine nitrate (9.07 kg) array

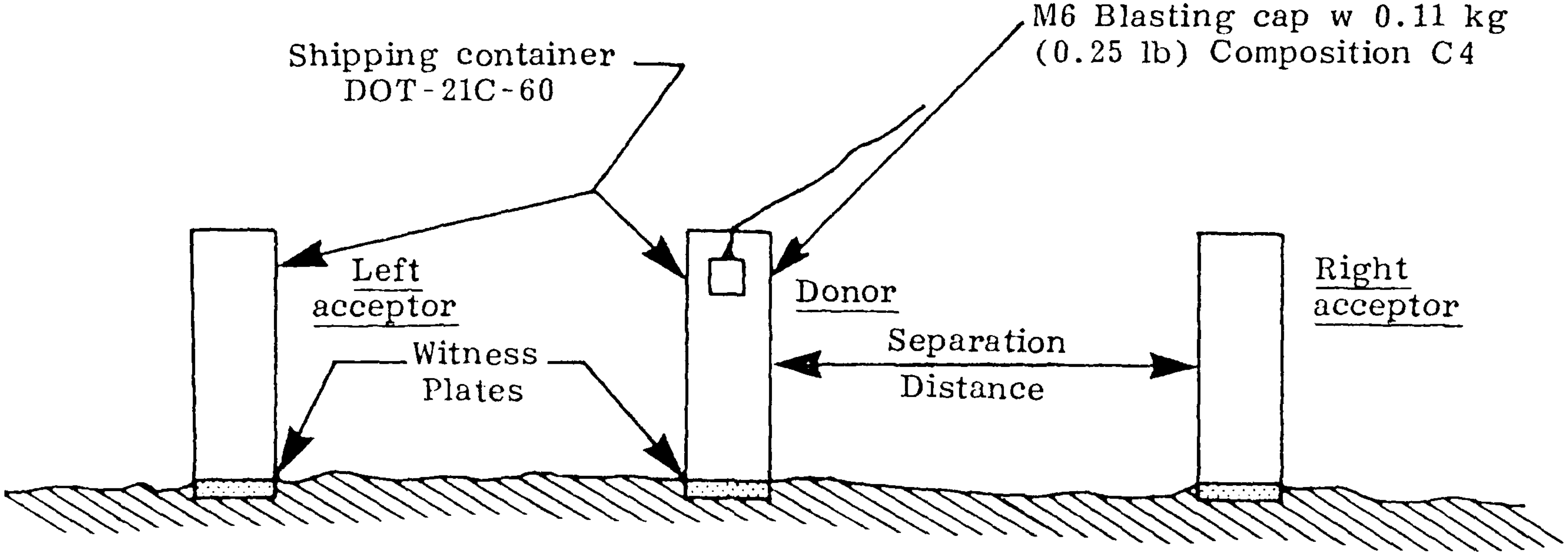

Figure 12. Nitroguanidine (11.3 kg) and guanidine nitrate (18.1 kg) array

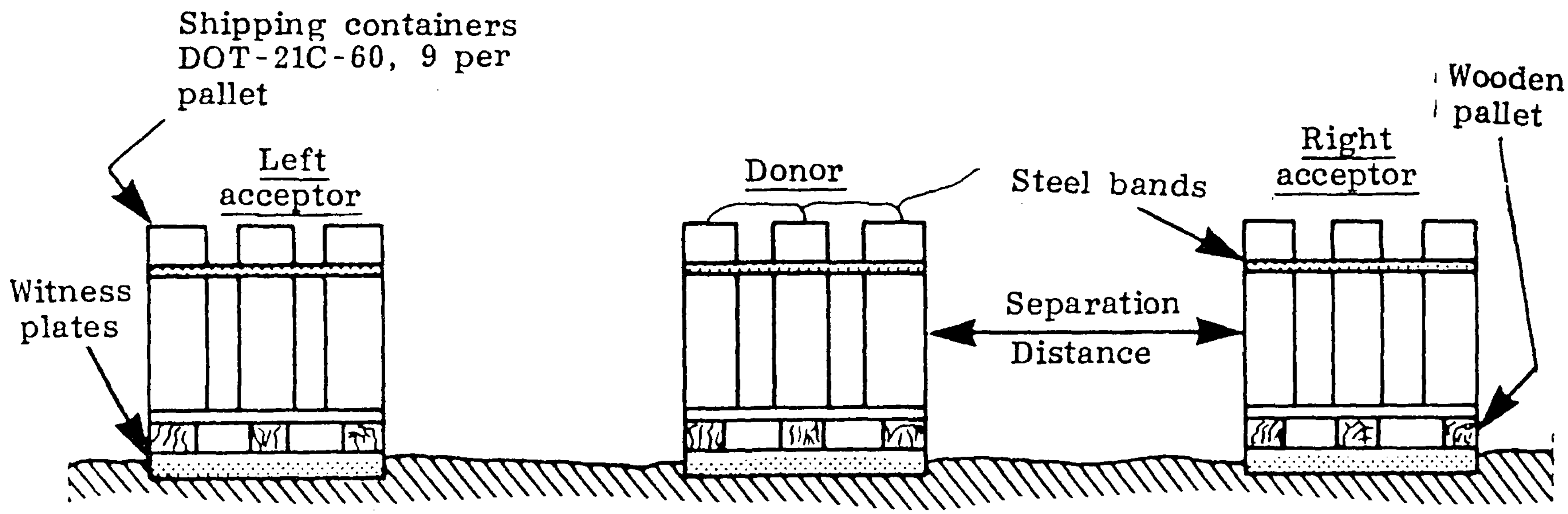

Figure 13. Nitroguandine (204.1 kg) array

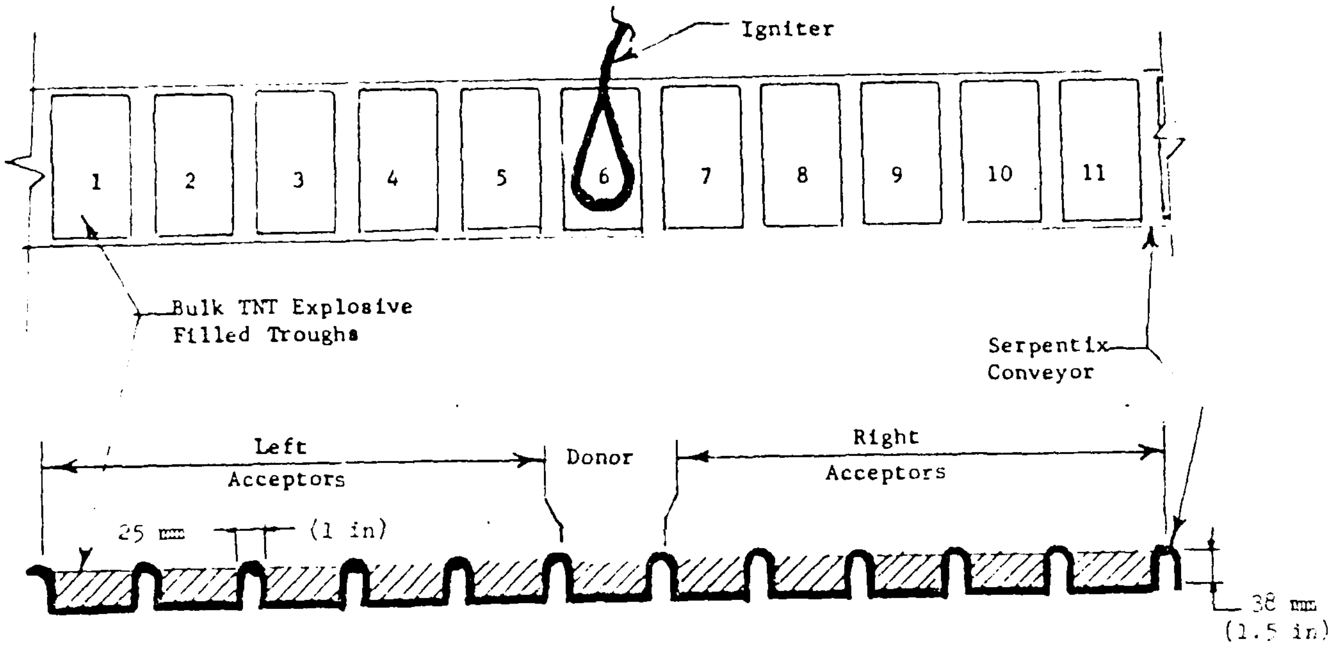

Figure 14. Serpentix conveyor layout

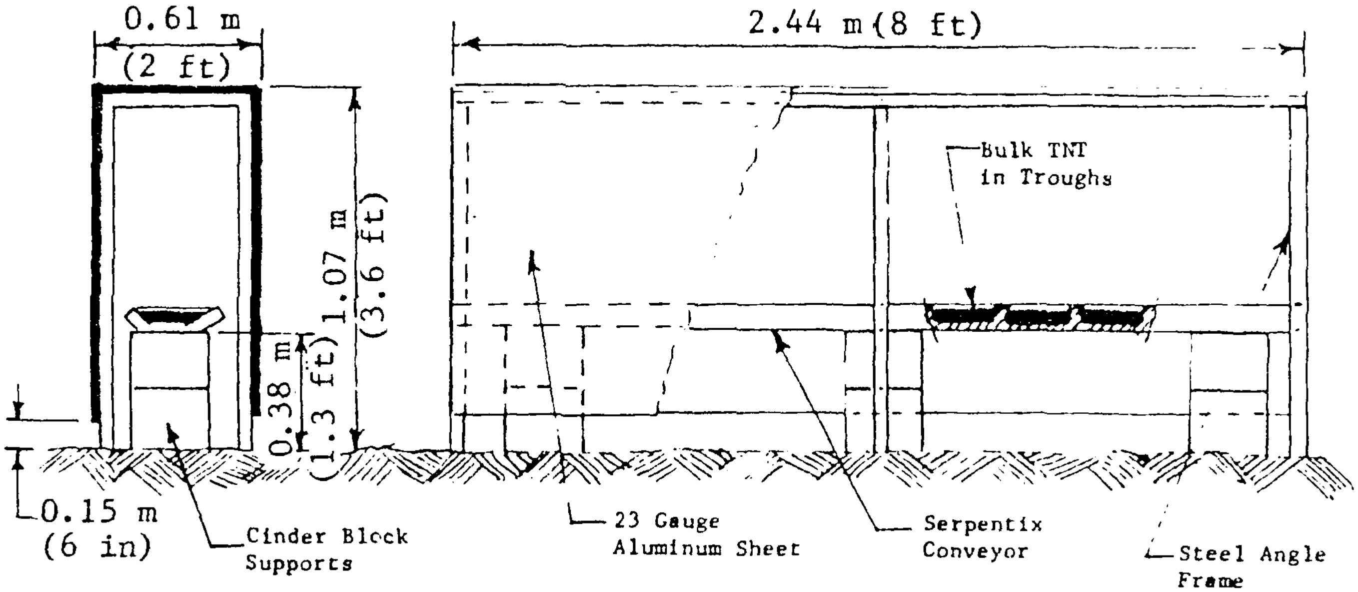

Figure 15. Simulated tunnel layout

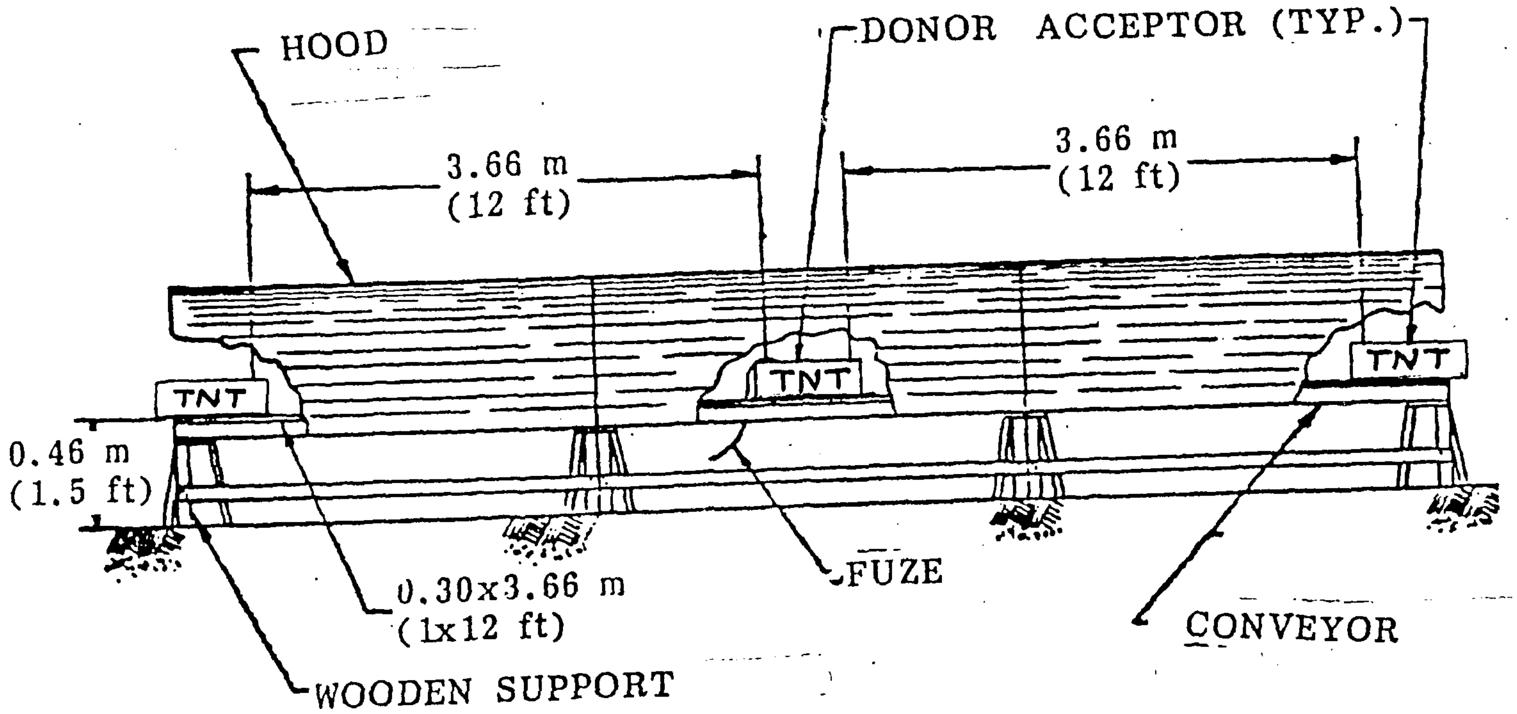

Figure 16. Conveyor setup bulk TNT

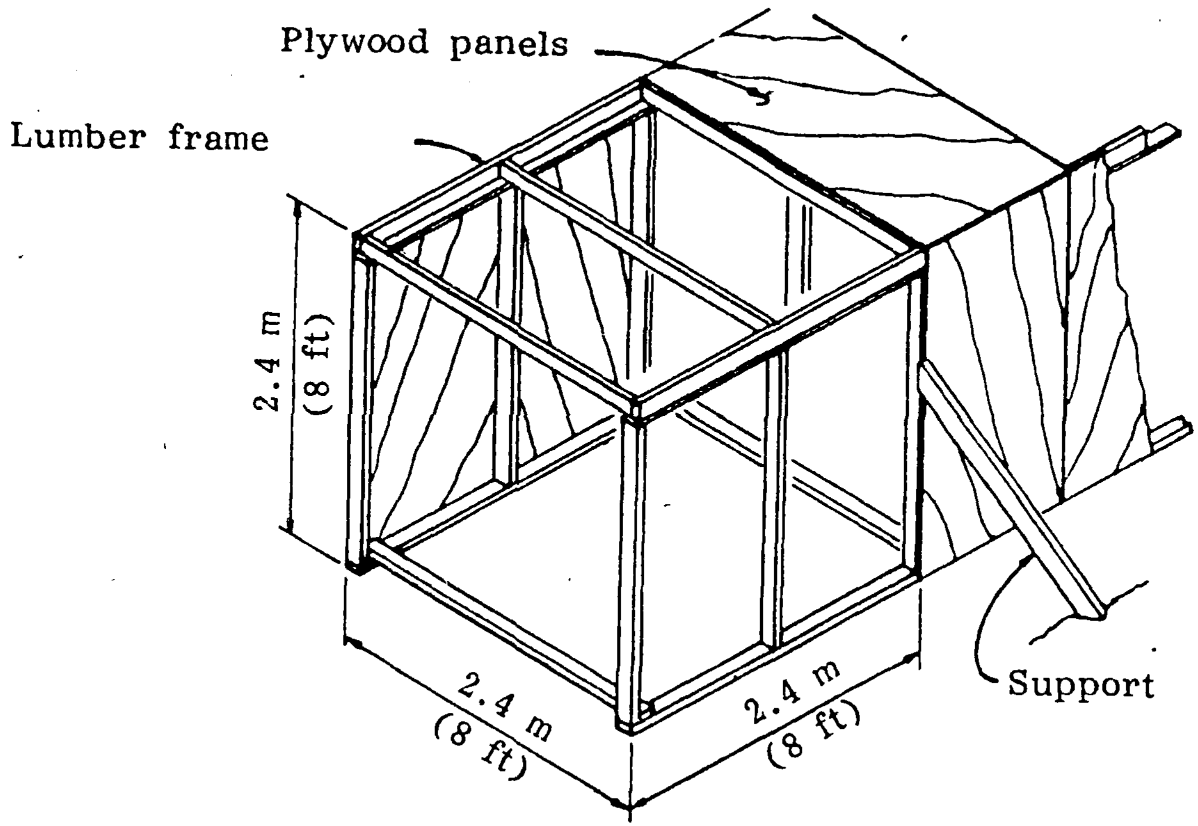

Figure 17. Wood-frame ramp

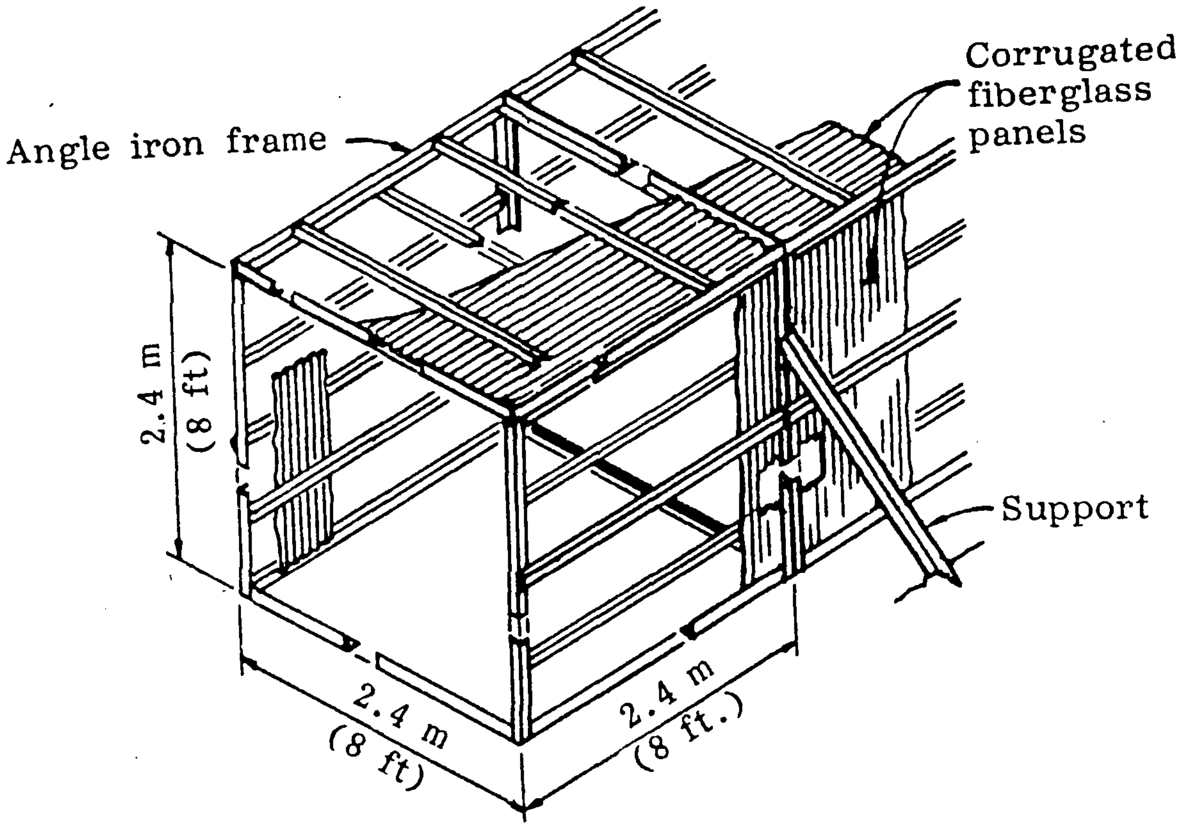

Figure 18. Steel-framed ramp

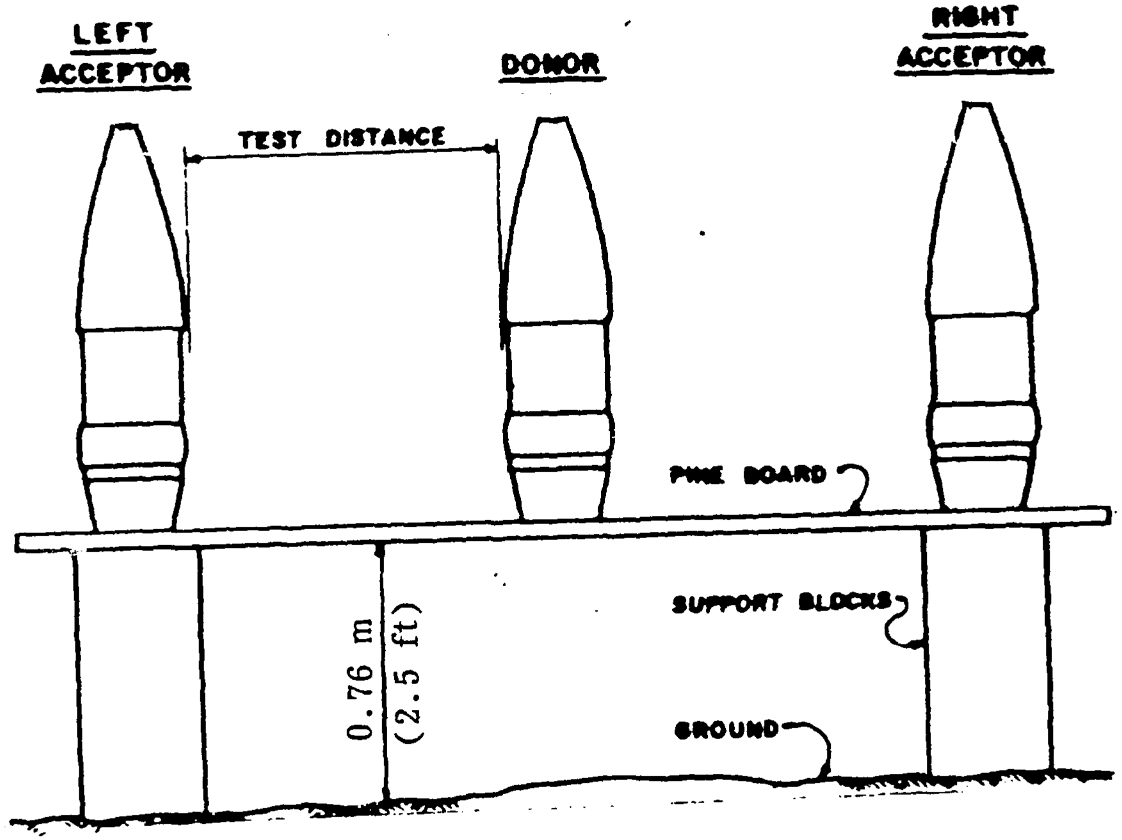

Figure 19. Projectile unshielded array

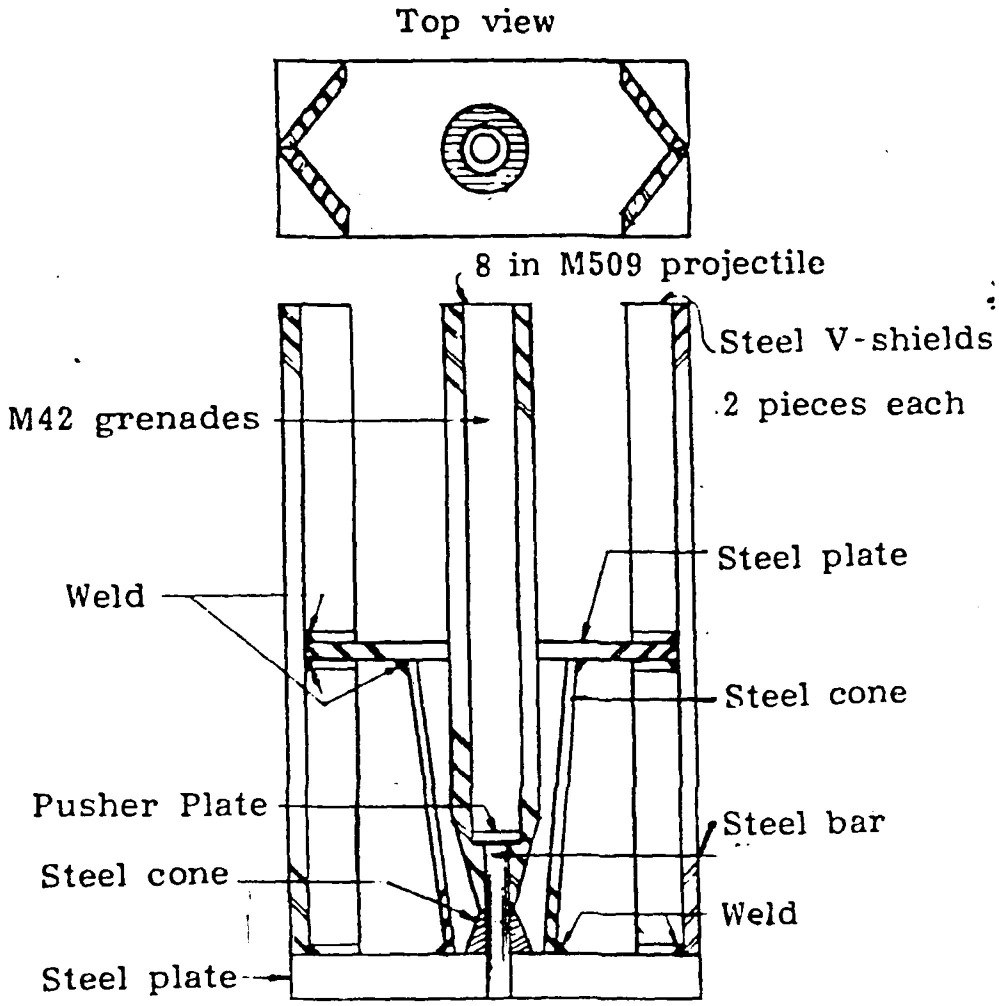

Figure 20. Transfer pellet with "V" shield

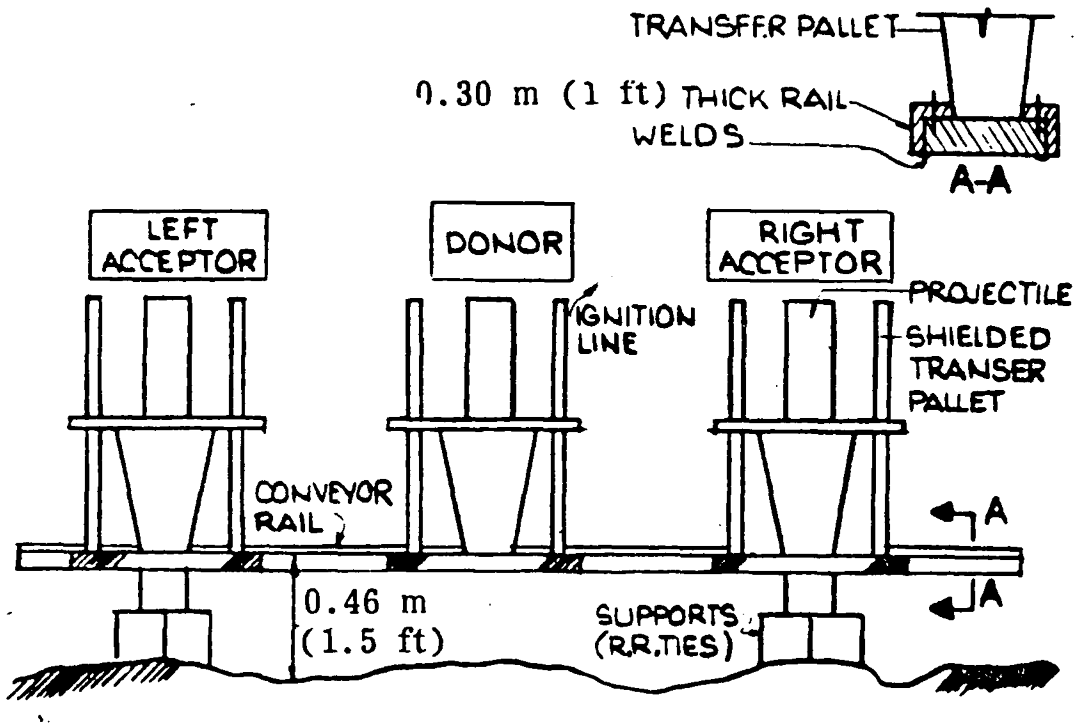

Figure 21. "V" shield array

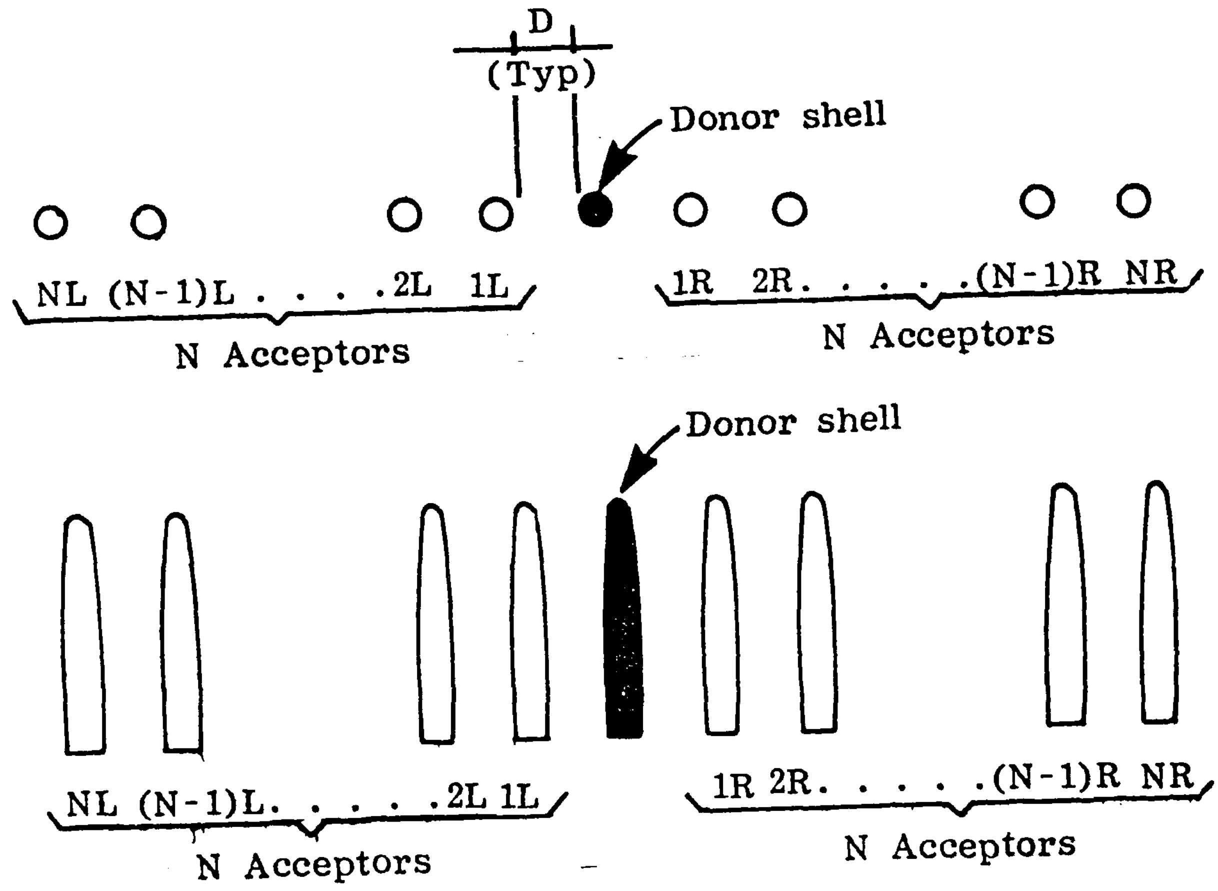

Figure 22. Domino orientations

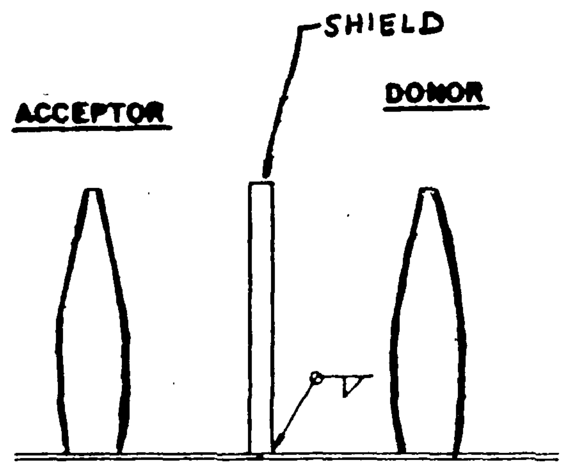

Figure 23. Shielded projectile array

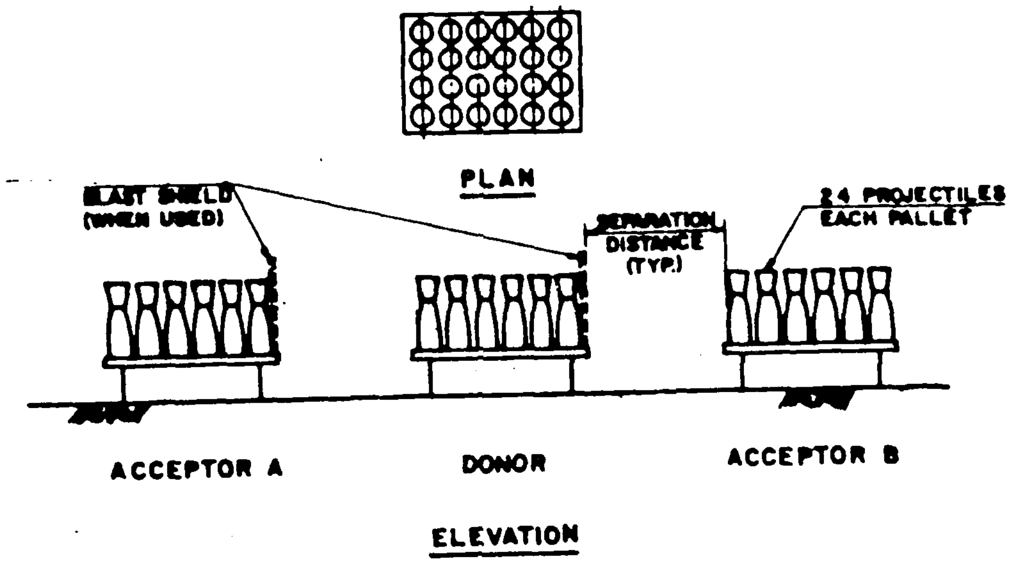

Figure 24. Pallet arrangement

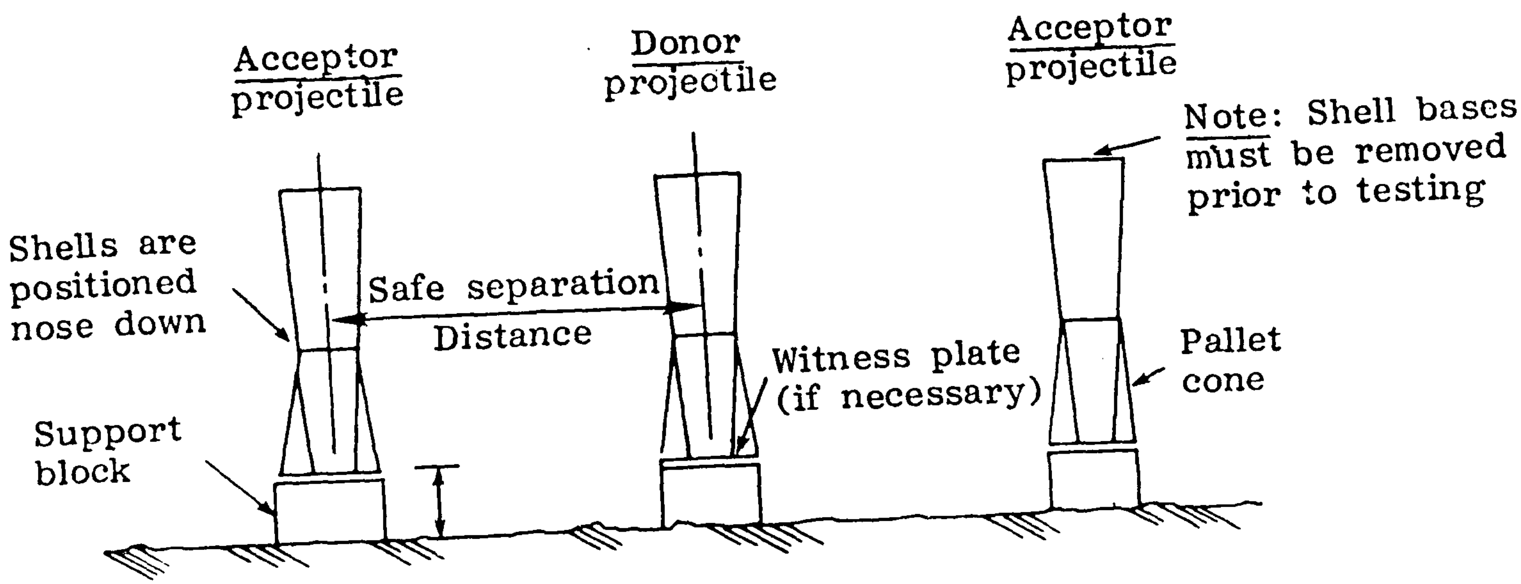

Figure 25. Phase 1 configuration

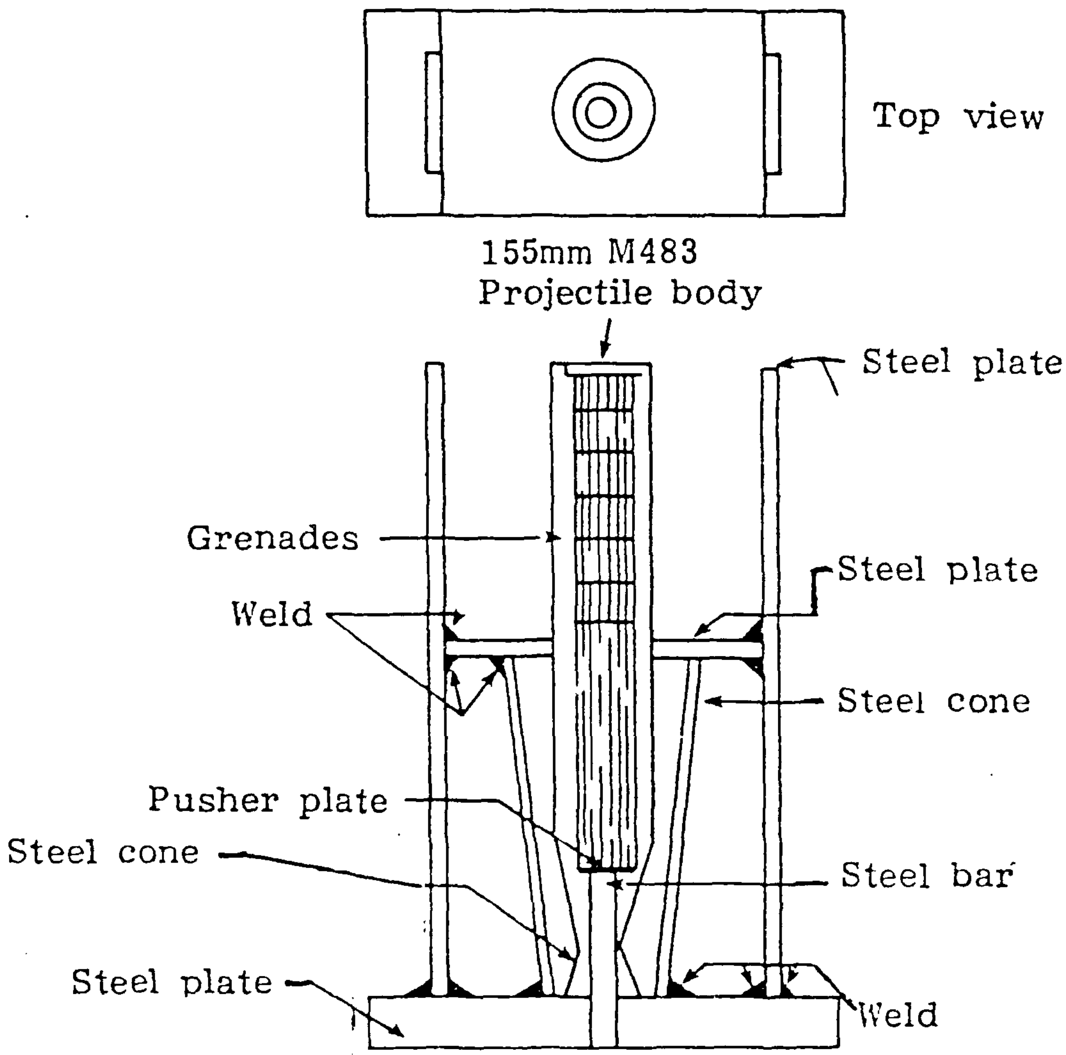

Figure 26. Pallet design

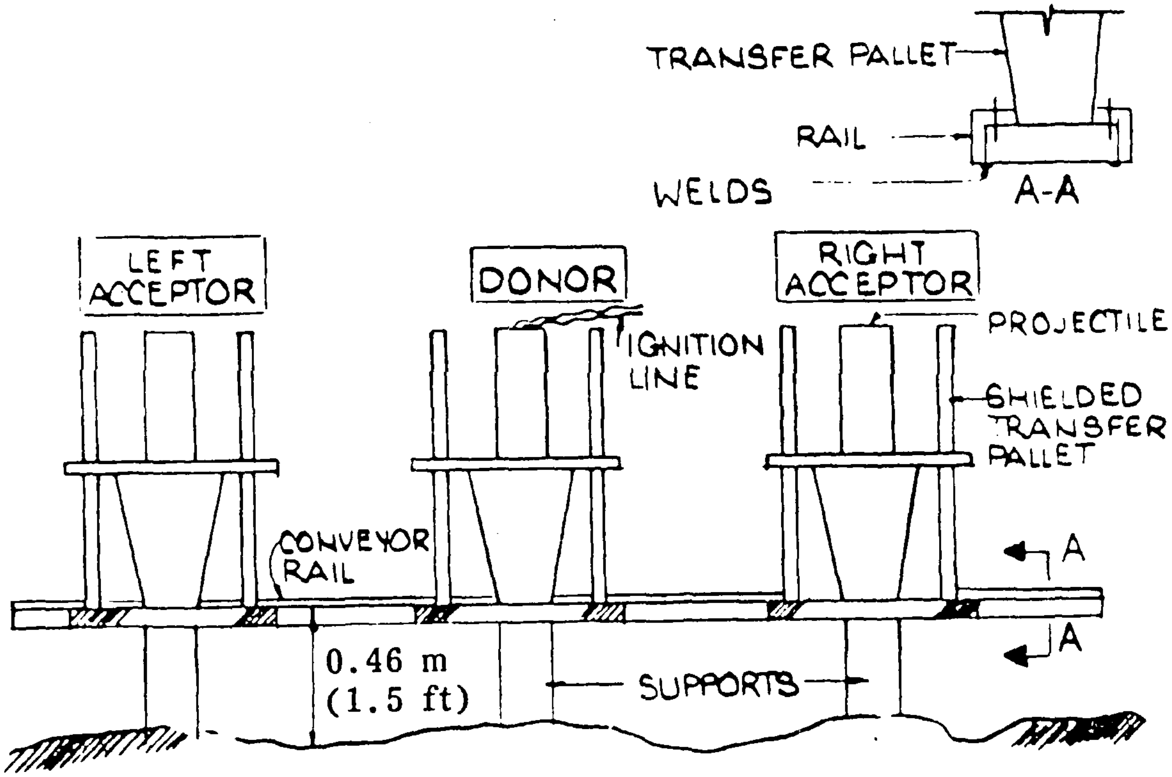

Figure 27. Phase 3 configuration

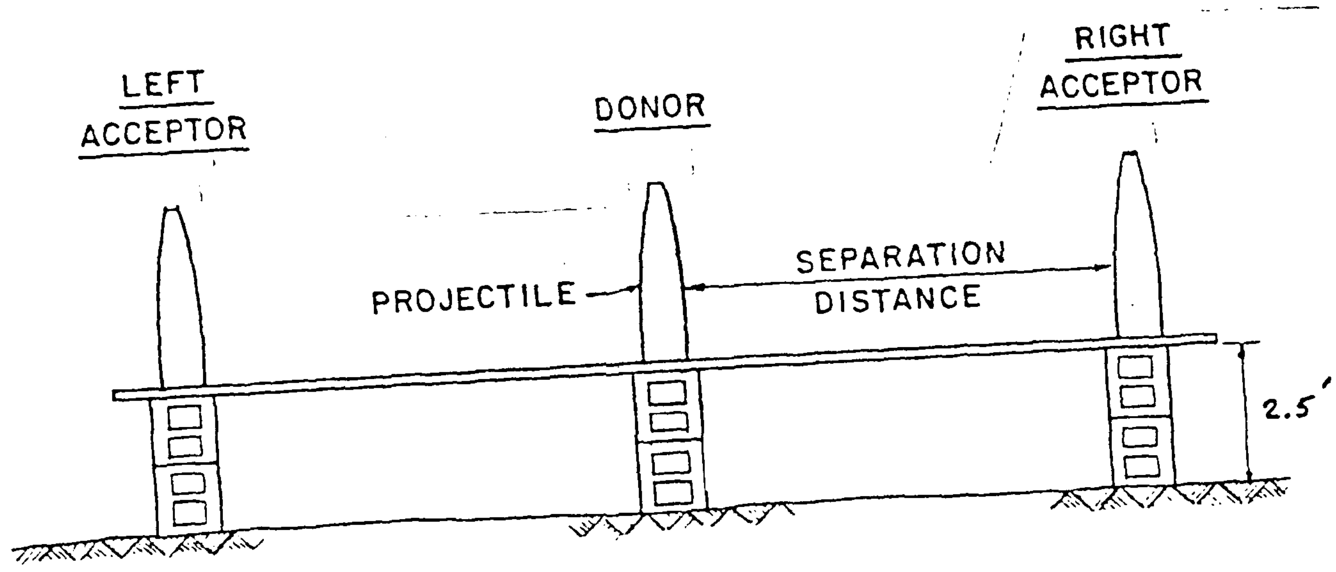

Figure 28. Single projectile array

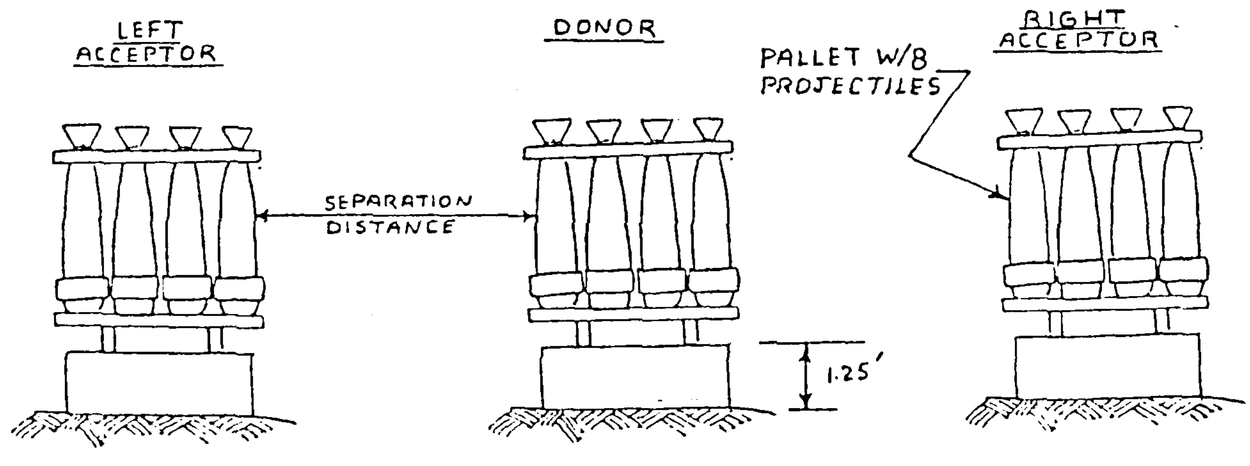

Figure 29. Pallet of eight array

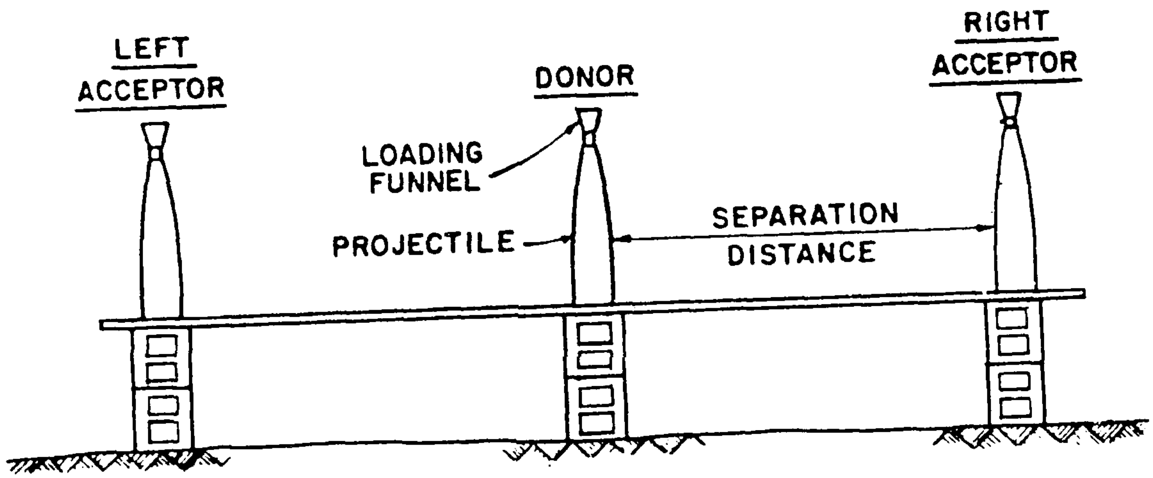

Figure 30. Projectile array

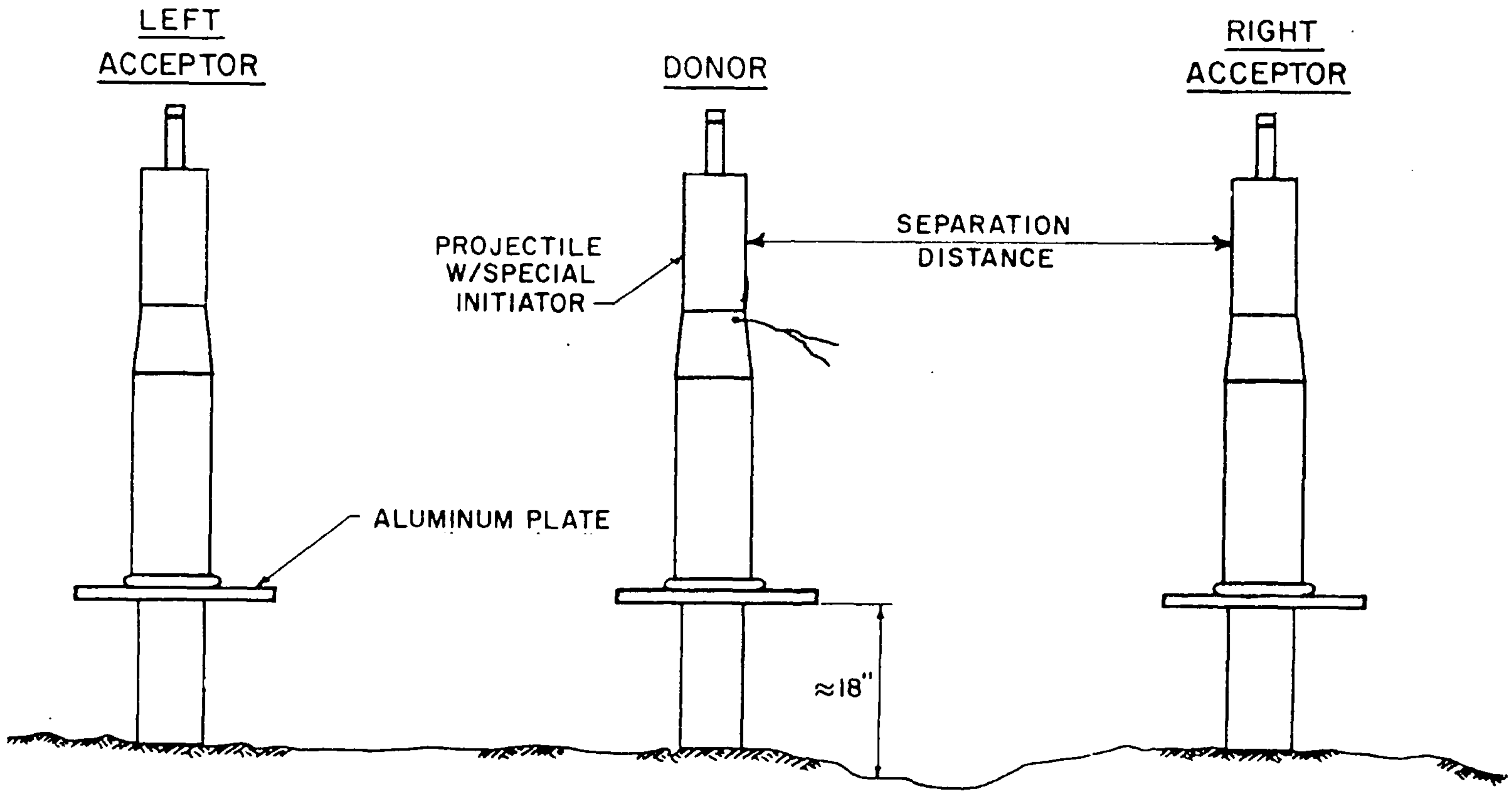

Figure 31. Vertical cartridge array

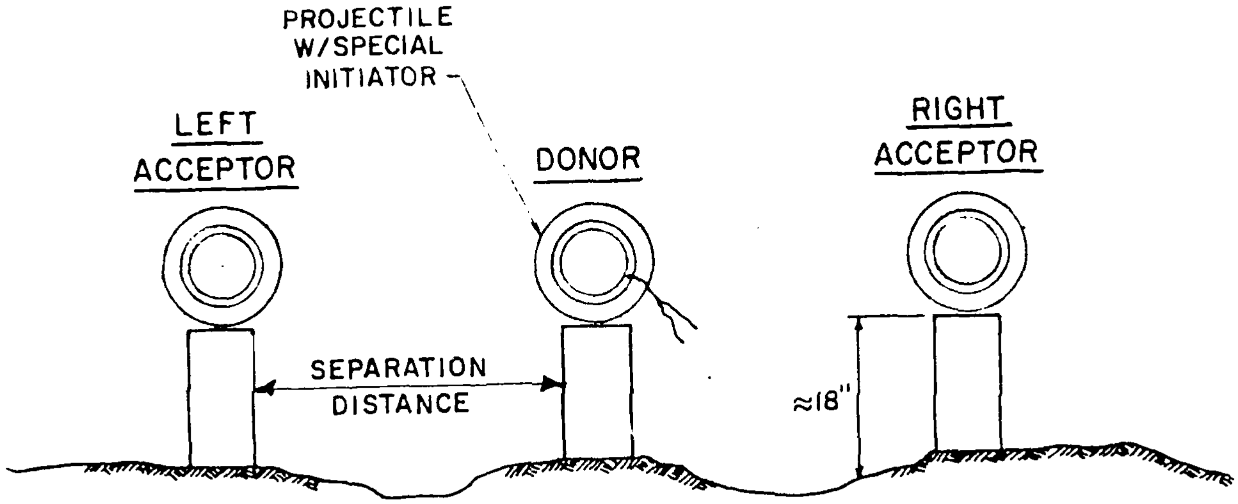

Figure 32. Horizontal cartridge array

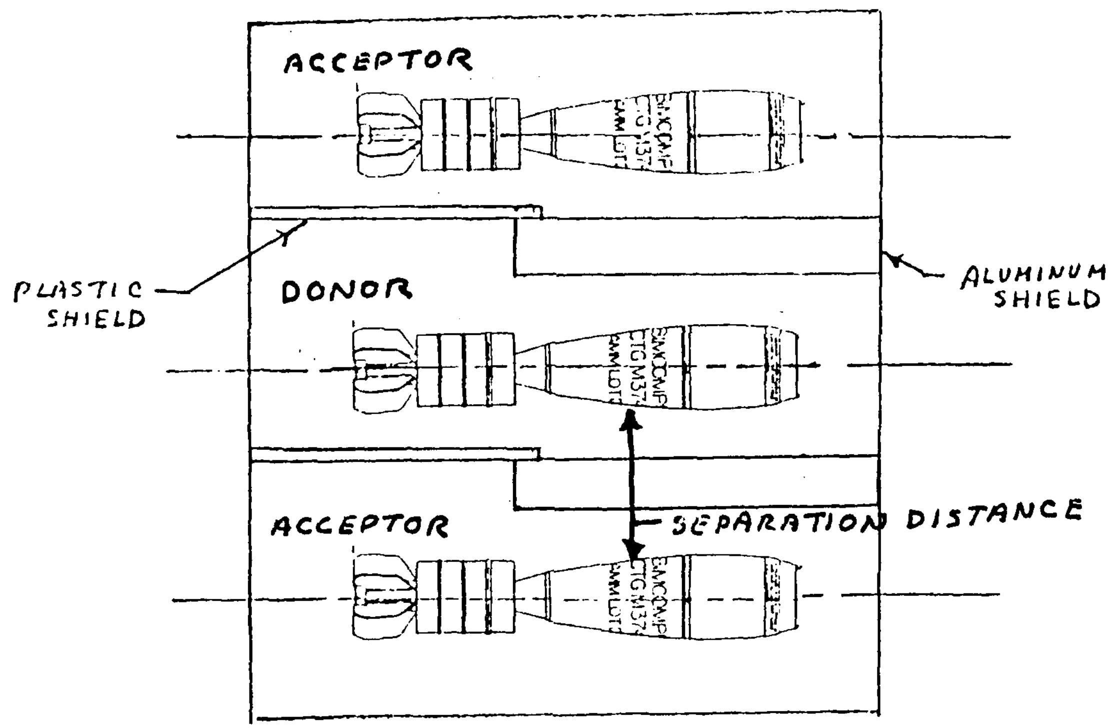

Figure 33. Transfer pallet

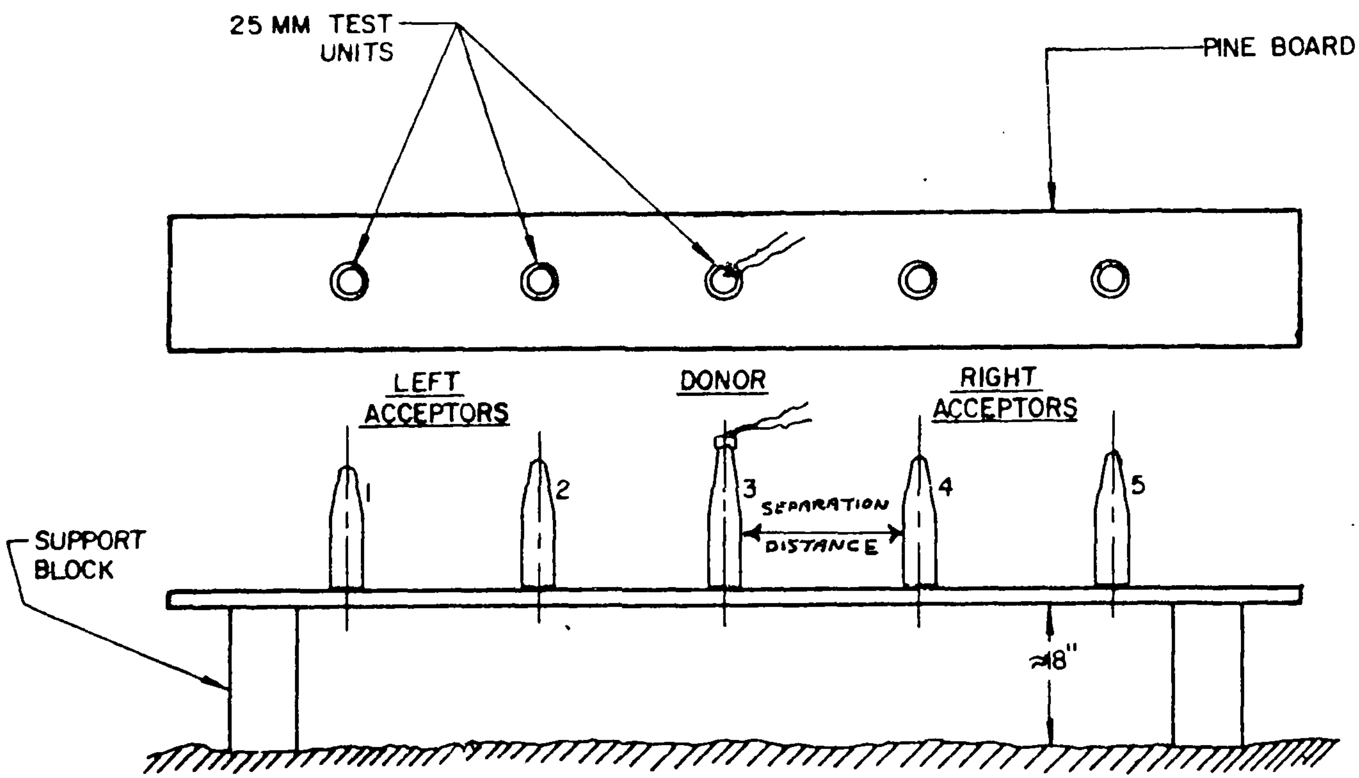

Figure 34. General array

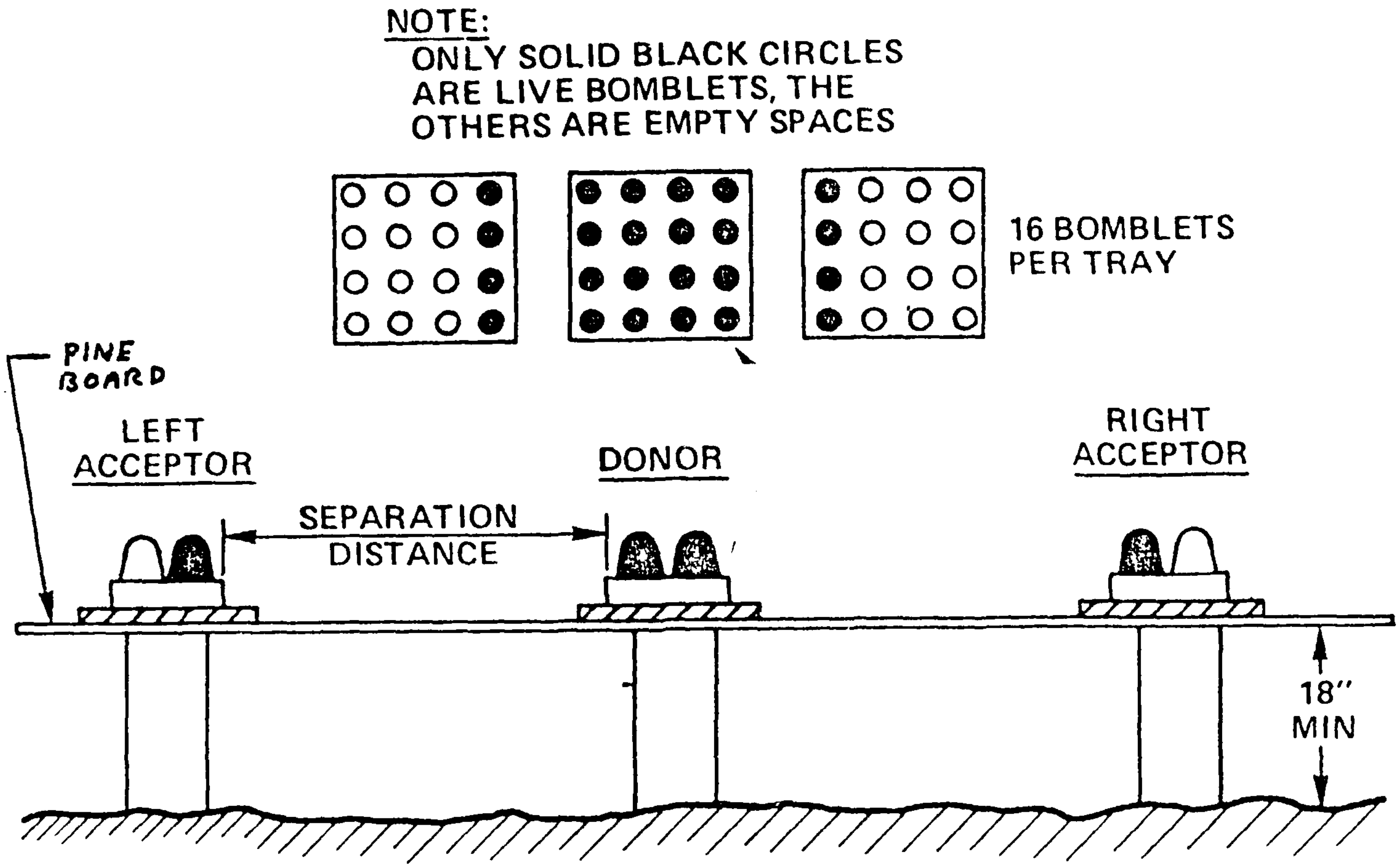

Figure 35. Submunition array

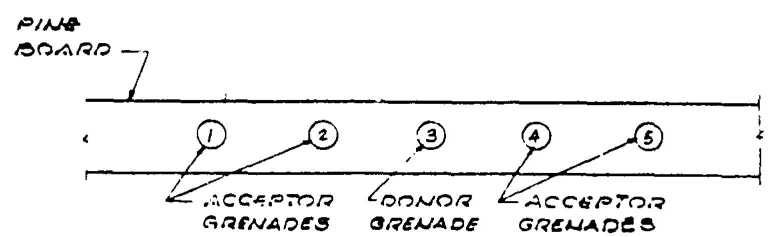

Figure 36. Setup for single grenades

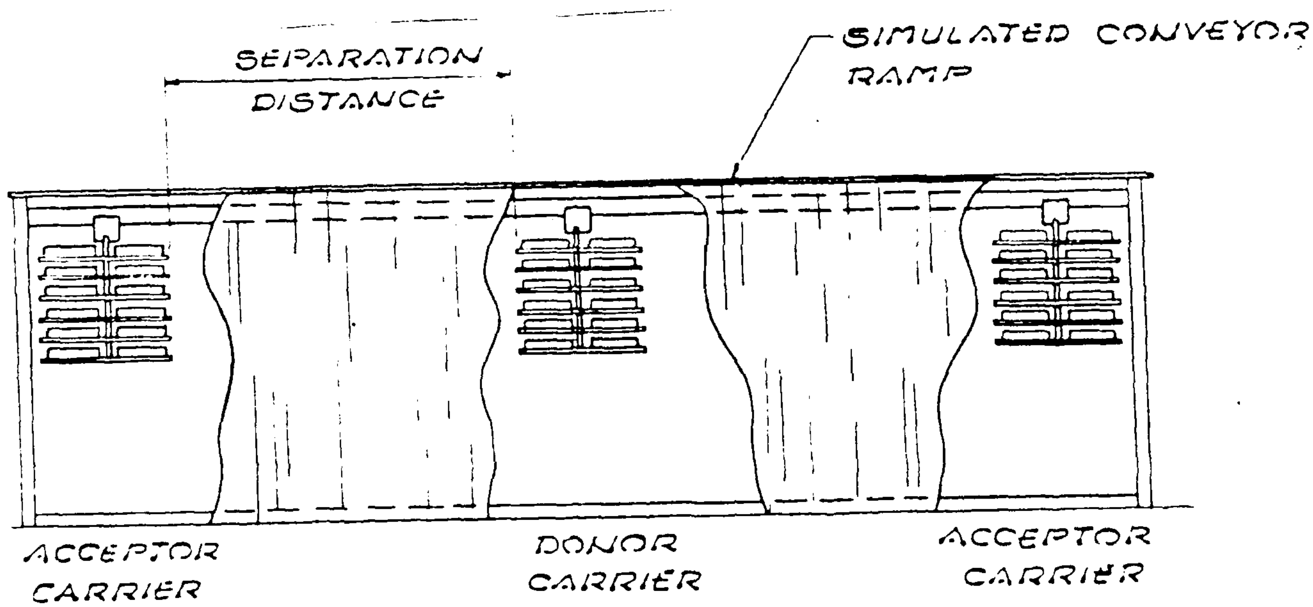

Figure 37. Setup for carriers with 12 trays

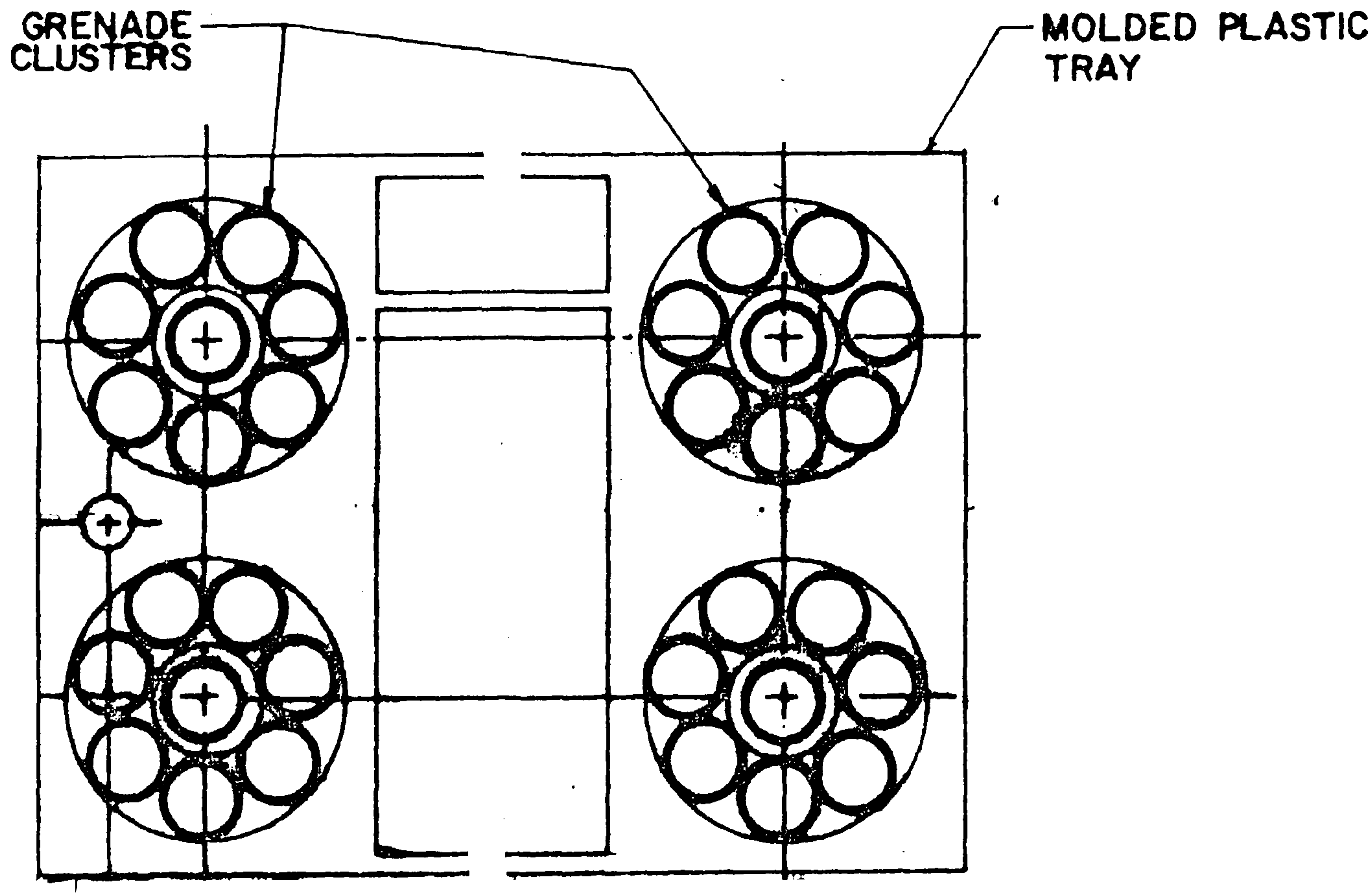

Figure 38. Cluster tray

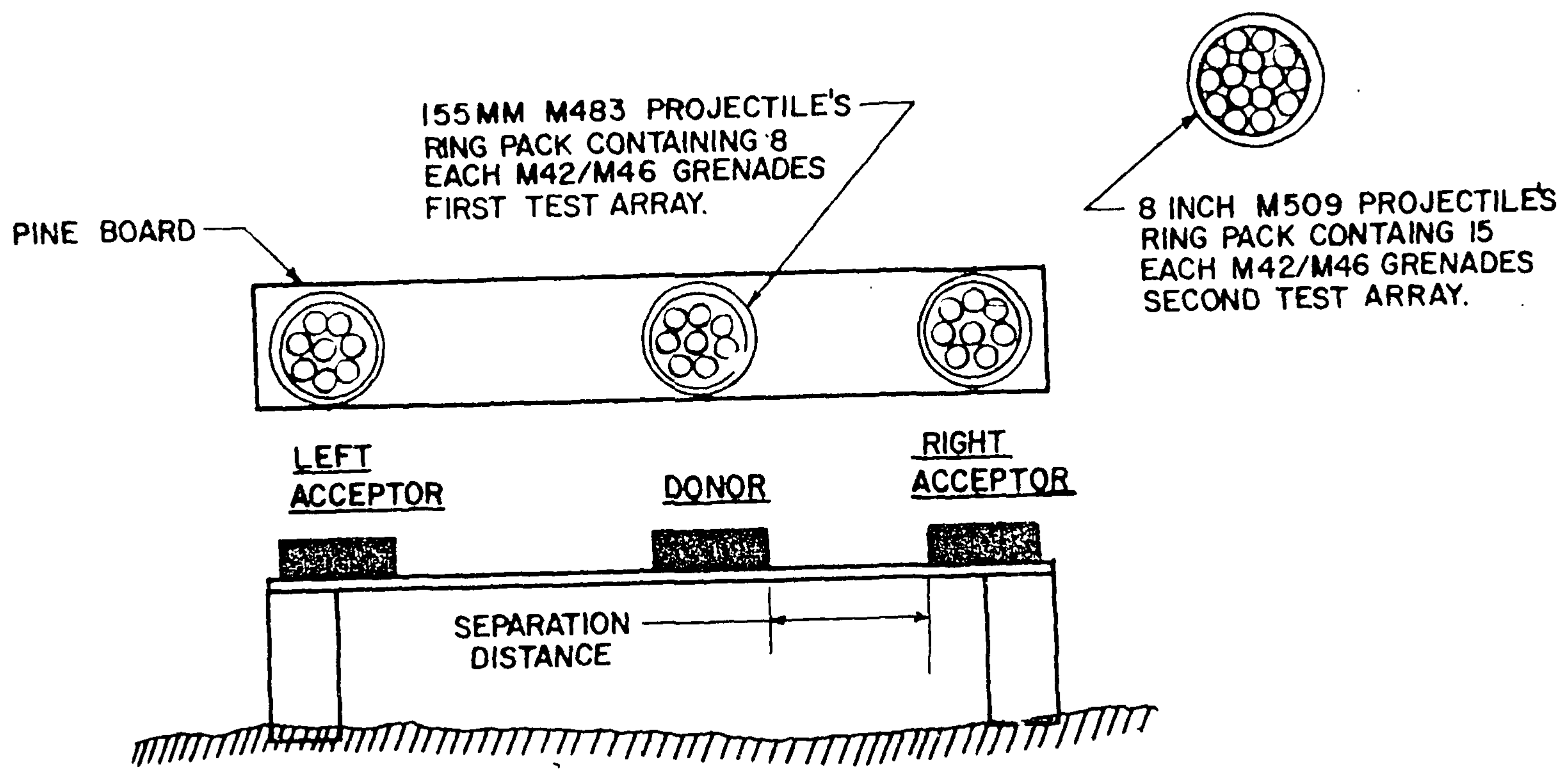

Figure 39. Ring pack

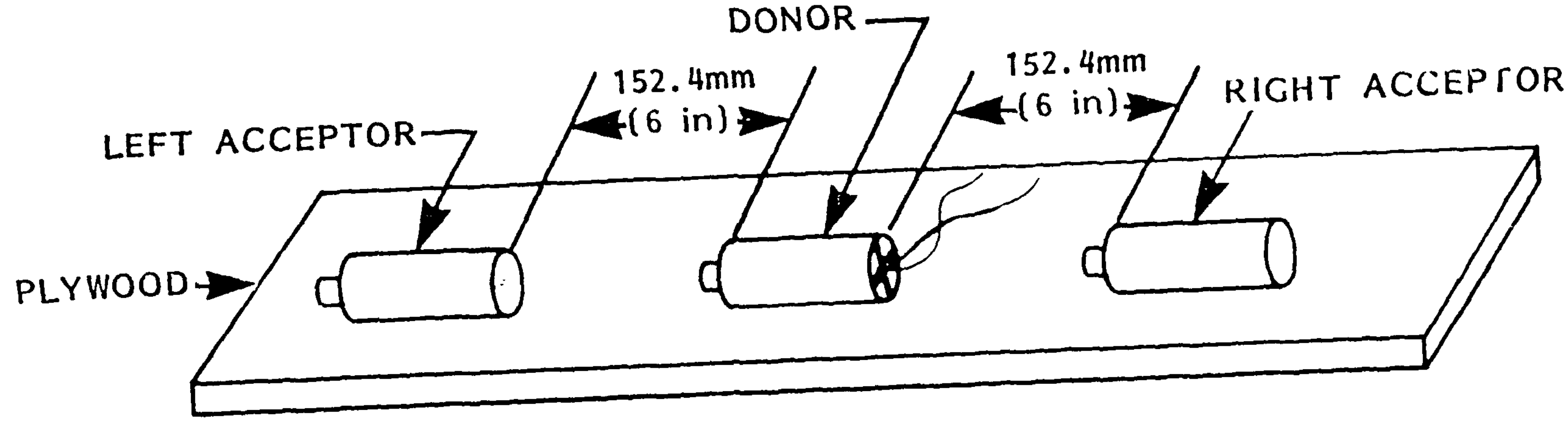

Figure 40. Mine setup

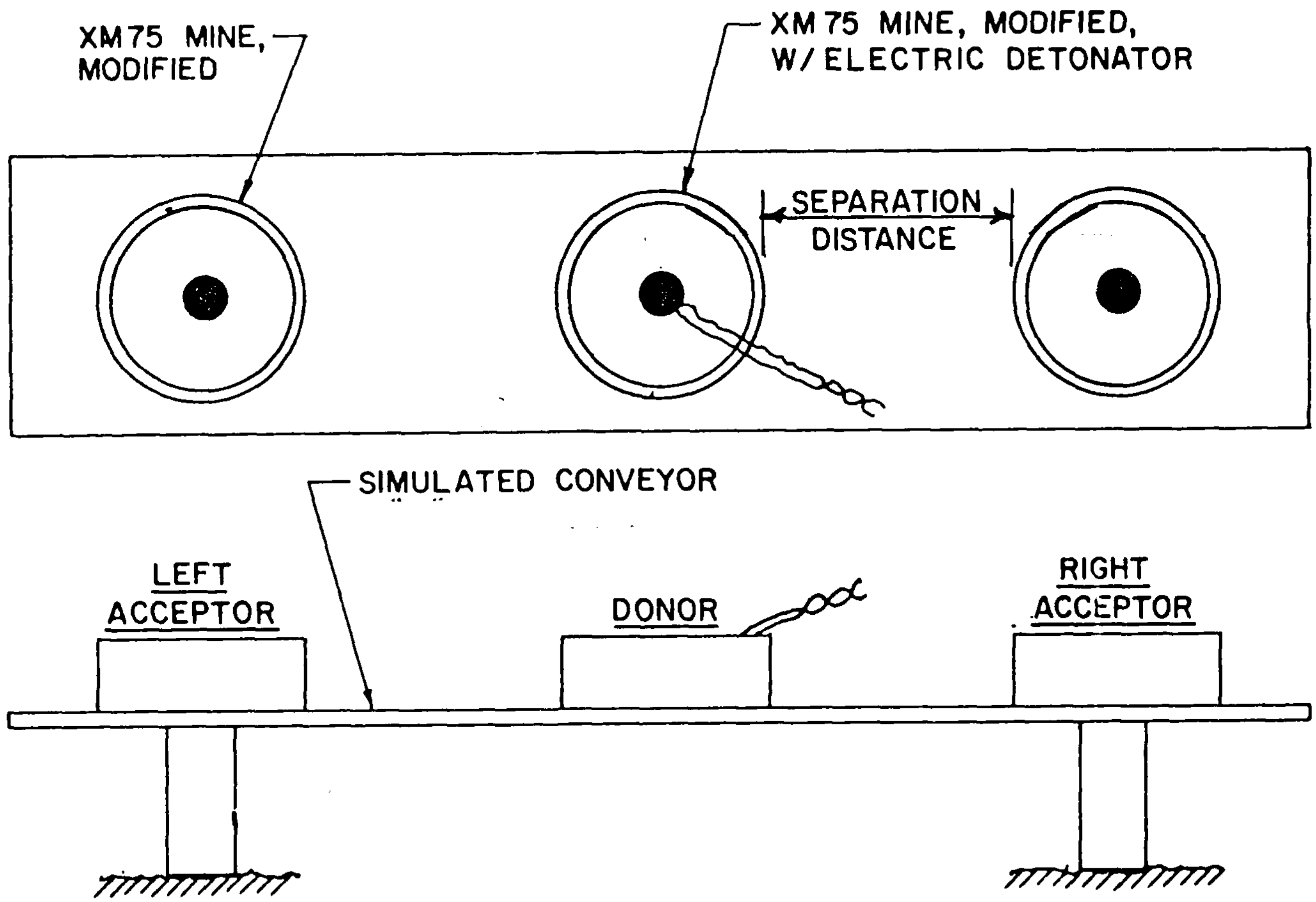

Figure 41. Unbarricaded mine setup

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